Radioactive Ion Beam Production by Neutron Induced Fission in Actinide Targets at EURISOL Multi-MW Converter Target

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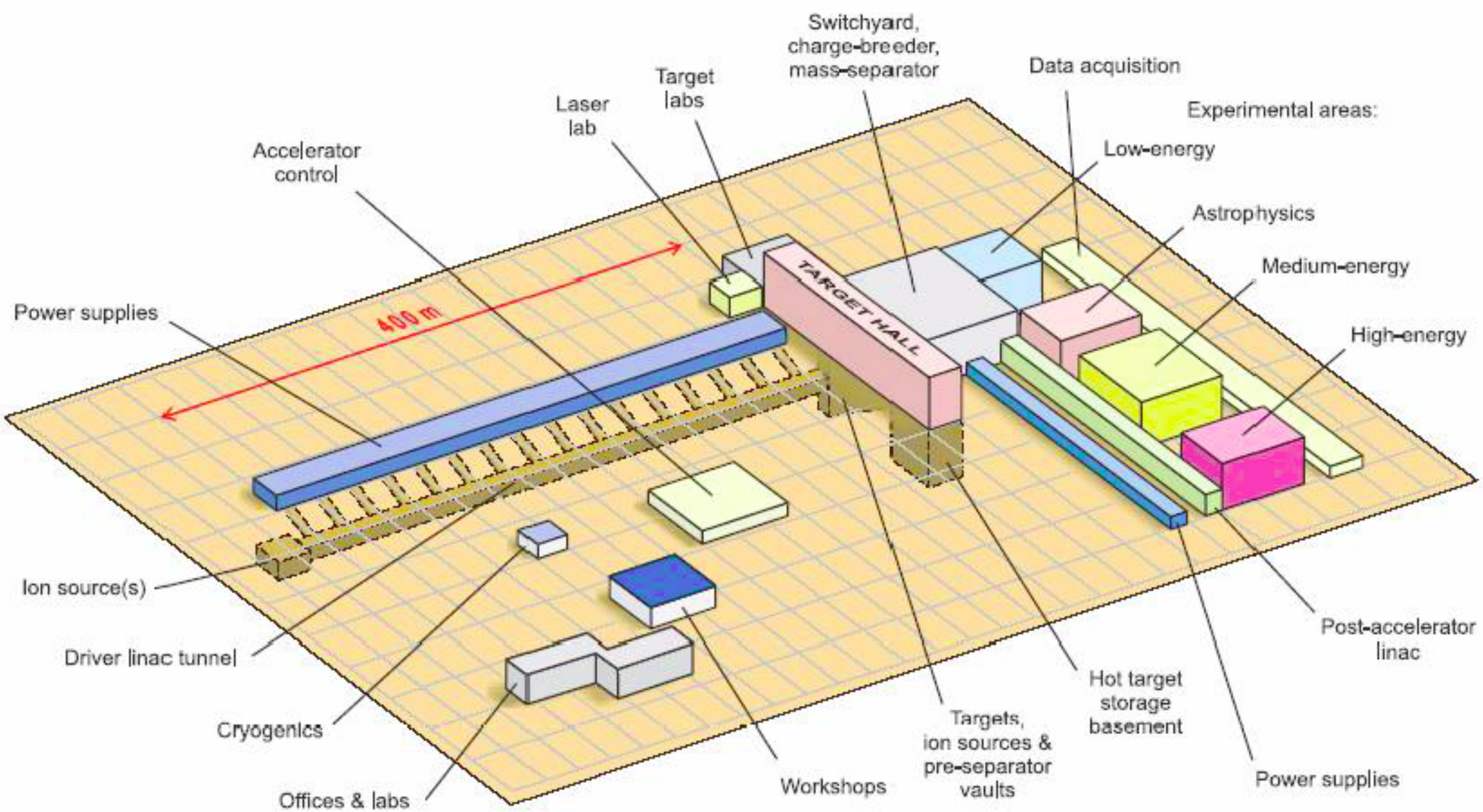
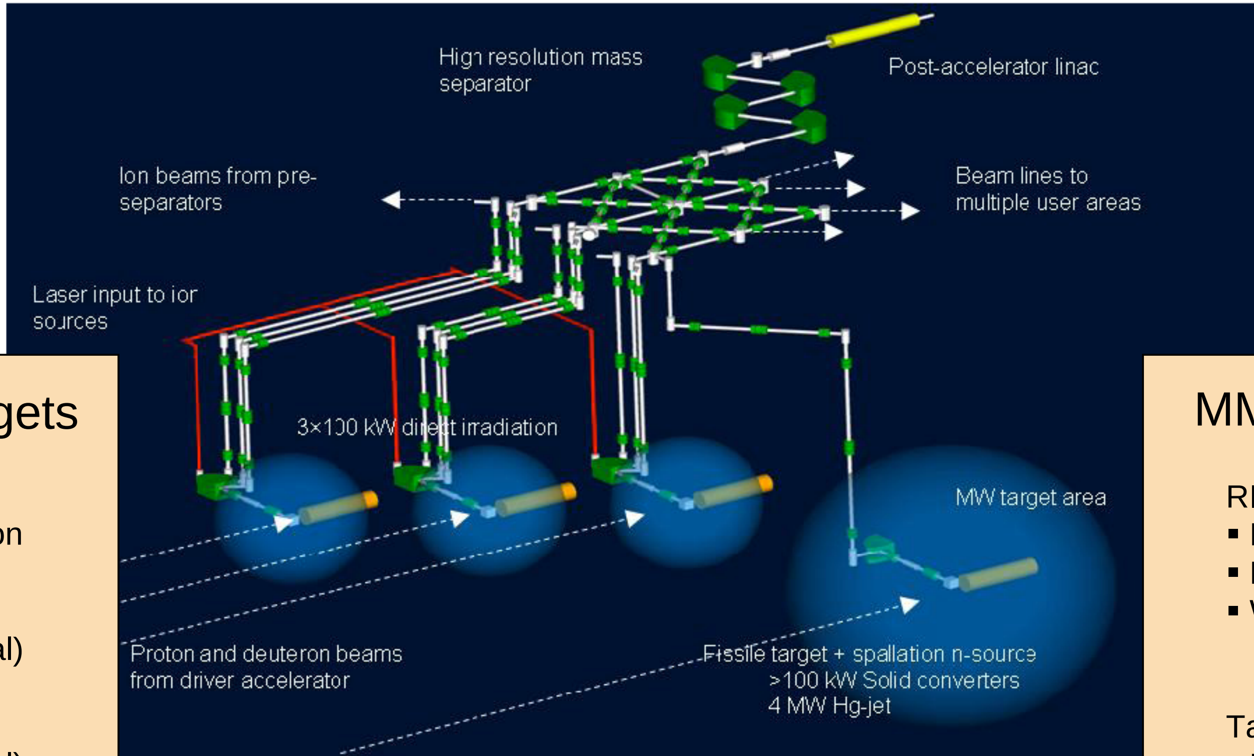
Buildings & Installations



Schematic drawing showing a possible layout of the EURISOL facility.

EURISOL Target Stations



100 kW direct targets

RIB production:
- Spallation-evaporation
- Main: P-rich
  (10 to 15 elements
  below target material)
- Residues: N-rich
  (A few elements
  below target material)

Target materials:
- Oxides
- Carbides
- Metal foils
- Liquid metals

MMW fission target

RIB production:
- Fission
- N-rich
- Wide range
  Z = 10 to Z = 60

Target material:
- U (baseline)
- Th

Converter:
- Hg

EURISOL-DS Targetry Challenges

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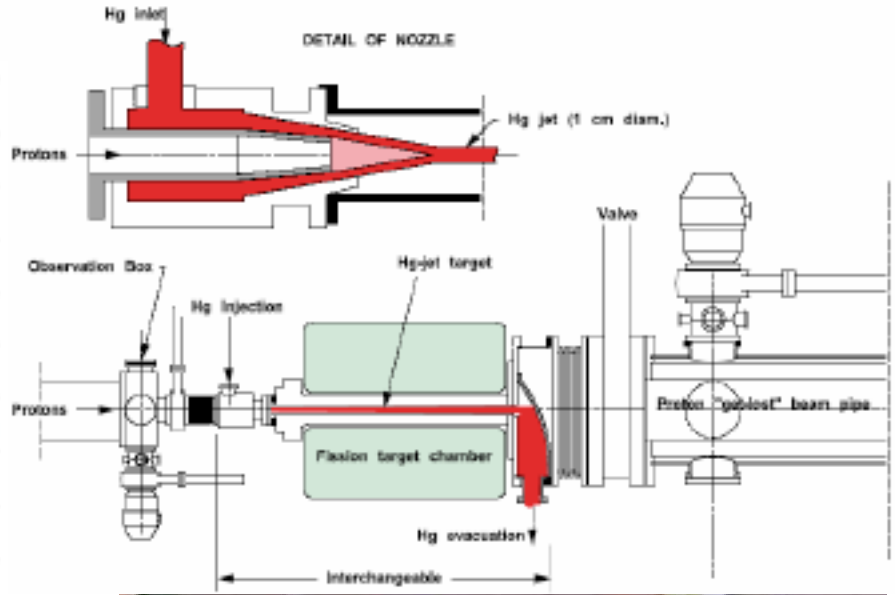
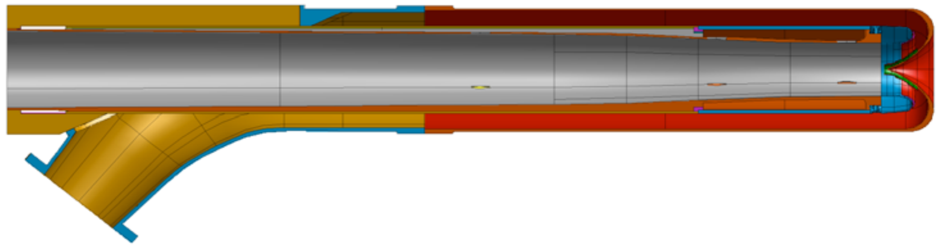
EURISOL shall deliver beams 3 orders of magnitude higher intensity than in presently operating facilities.

Parameter	Symbol	Units	Nval	Range
Converter Target material	Z_{conv}	-	Hg (liquid)	LBE
Secondary Target material	Z_{targ}	-	UC_x, BeO	
Beam particles	Z_{beam}	-	Proton	
Beam particle energy	E_{beam}	GeV	1	2
Beam current	I_{beam}	mA	4	2 – 5
Beam time structure	-	-	CW	50Hz 1ms pulse
Gaussian beam geometry	σ_{beam}	mm	15	< 25, parabolic
Beam power	P_{beam}	MW	4	< 5
Converter length	l_{conv}	cm	45	85
Converter radius (cylinder)	r_{conv}	cm	8	4 – 15
Hg temperature	T_{conv}	°C	150 – 200	<< 357
Hg flow rate	Q_{conv}	ton/s	0.1 – 0.2	<< 1
Hg speed	V_{conv}	m/s	~5	<< 15
Hg pressure drop	ΔP_1	bar	1 – 2	< 10
Hg overpressure	ΔP_2	bar	5 – 7	< 10
UC_x temperature	T_{targ}	°C	2000	500-2500



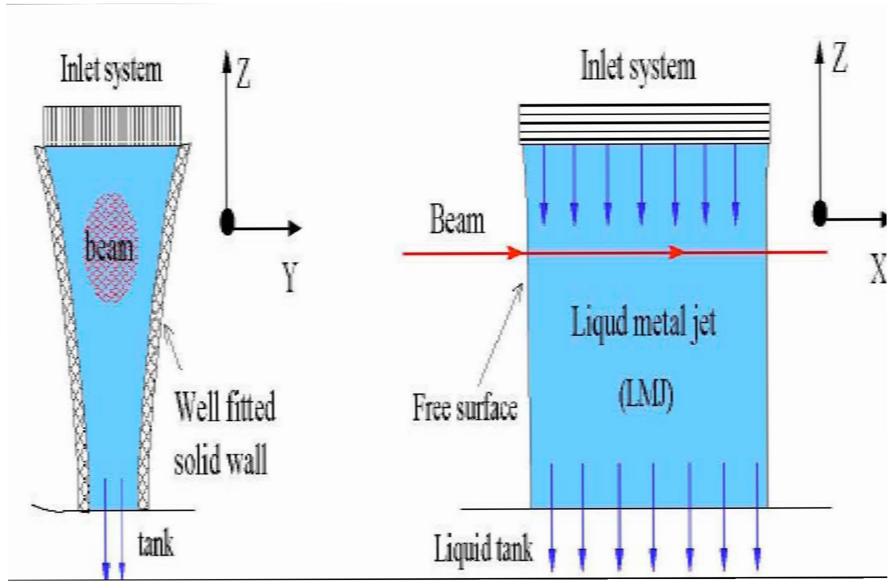
Task#2 – Multi-MW Liquid Hg Target

- Compact Hg-loop with beam widow
- Confined transverse film windowless



Deliverables:

1. Engineering study of the thermal hydraulics, fluid dynamics and construction materials of a window or window-free liquid-metal converter.
2. Study of an innovative waste management in the liquid Hg-loop e.g. by means of Hg distillation.
3. Engineering design and construction of a functional Hg-loop.
4. Off-line testing and validation of the thermal hydraulics and fluid dynamics.
5. Engineering design of the entire target station and its handling method

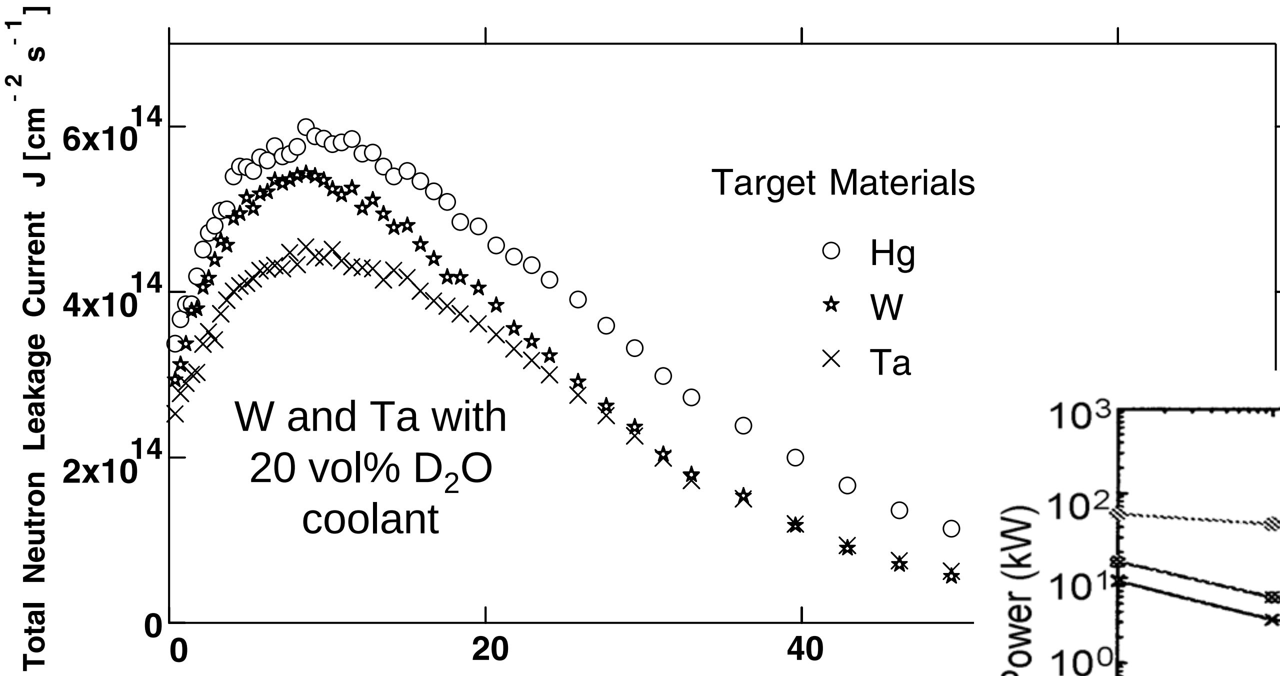


The choice of Hg as a Target (1)

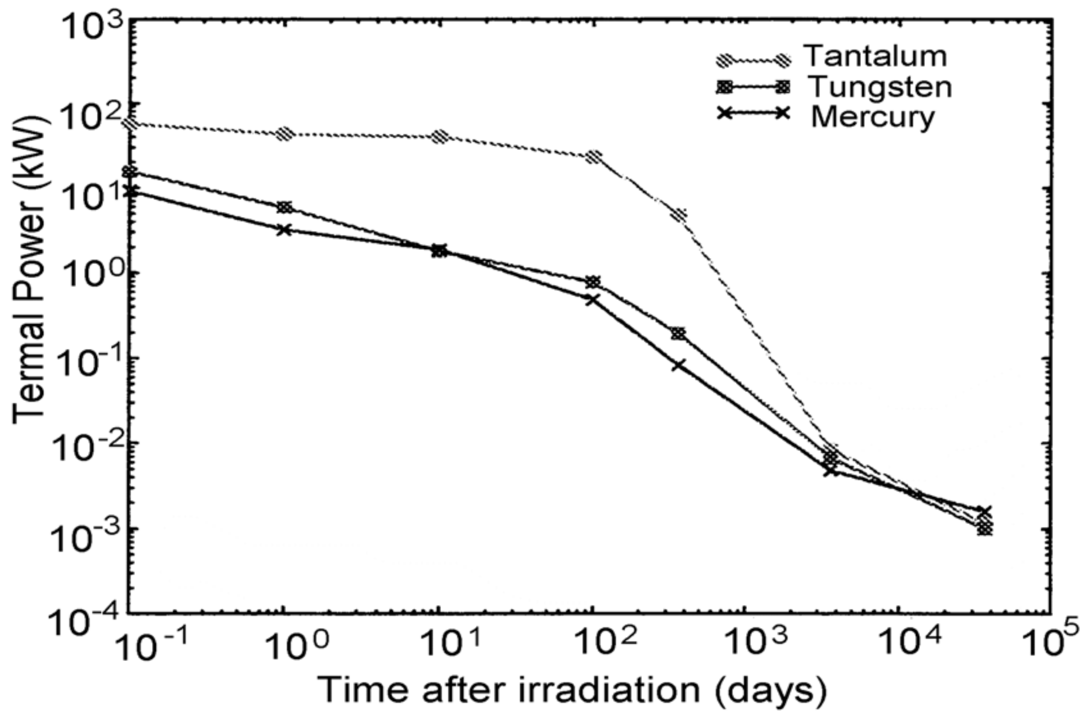
EURISOL Design Study

- Mercury has the highest density of all heavy liquid metals and hence produces the brightest neutron source
- Mercury is liquid at room temperature and hence needs no auxiliary heating
- Mercury produces practically no alpha-emitters with any sizable life time
- Mercury has a relatively low decay heat and no long lived radioactive isotopes
- Technical feasibility of Hg purification ➡ should be verified

The choice of Hg as a Target (2)

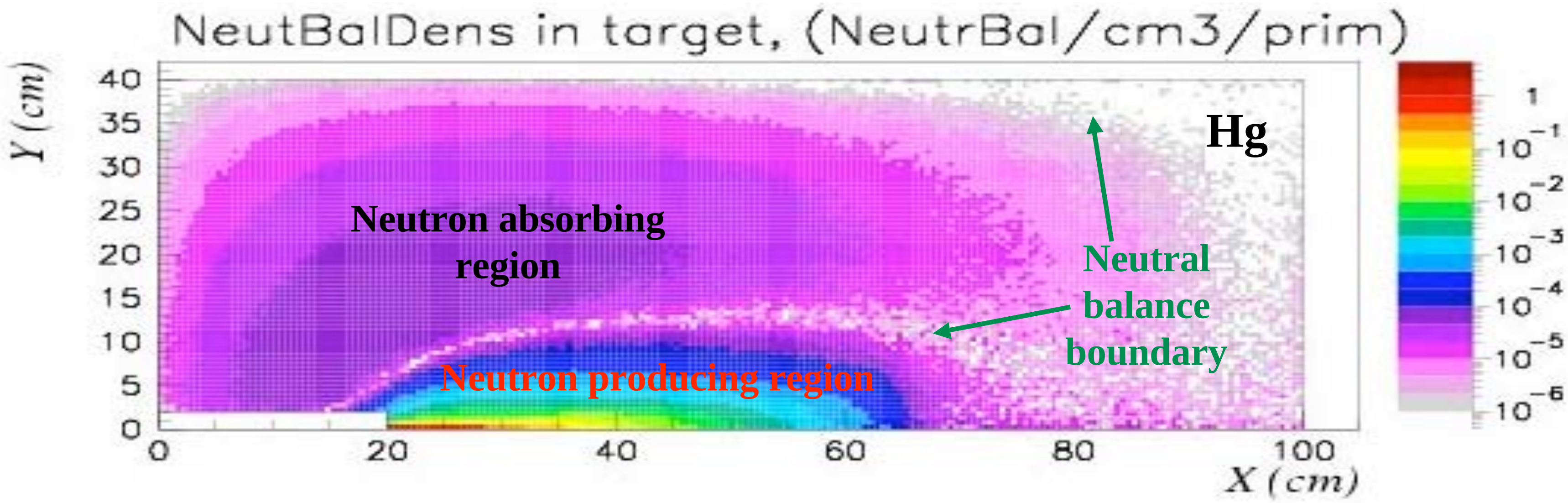


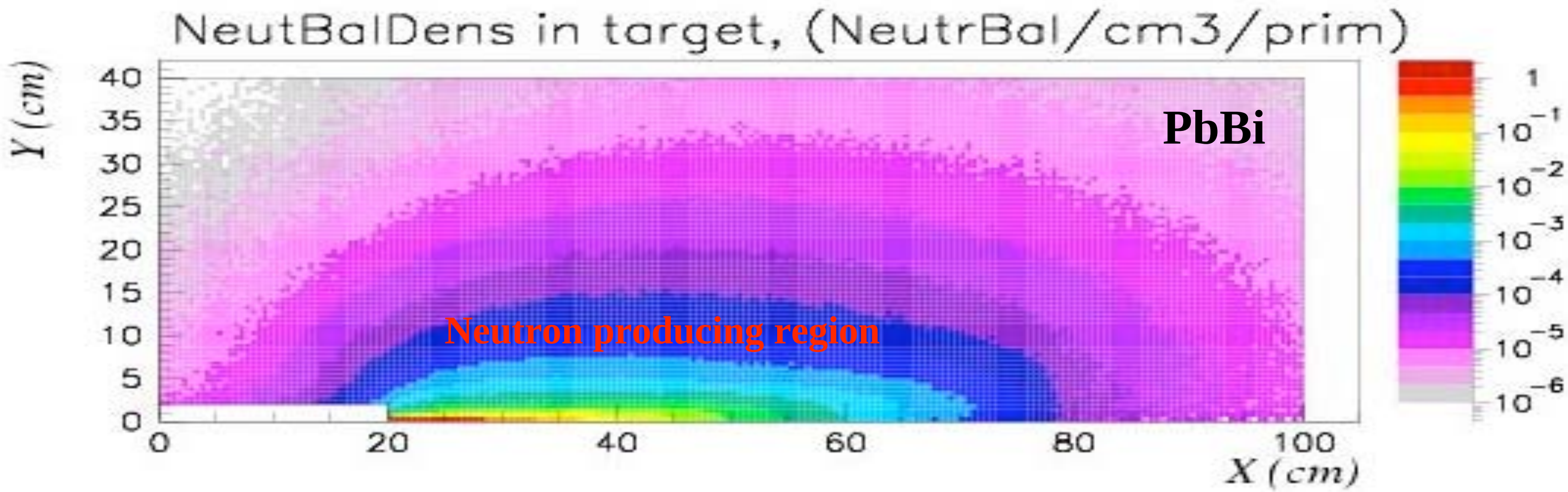
Calculated neutron leakage from a target of ESS geometry for different target materials



Calculated decay power for 200 days of operation in a 5 MW beam

PbBi Alternative – Neutron Balance





PbBi Alternative – Neutron Spectrum

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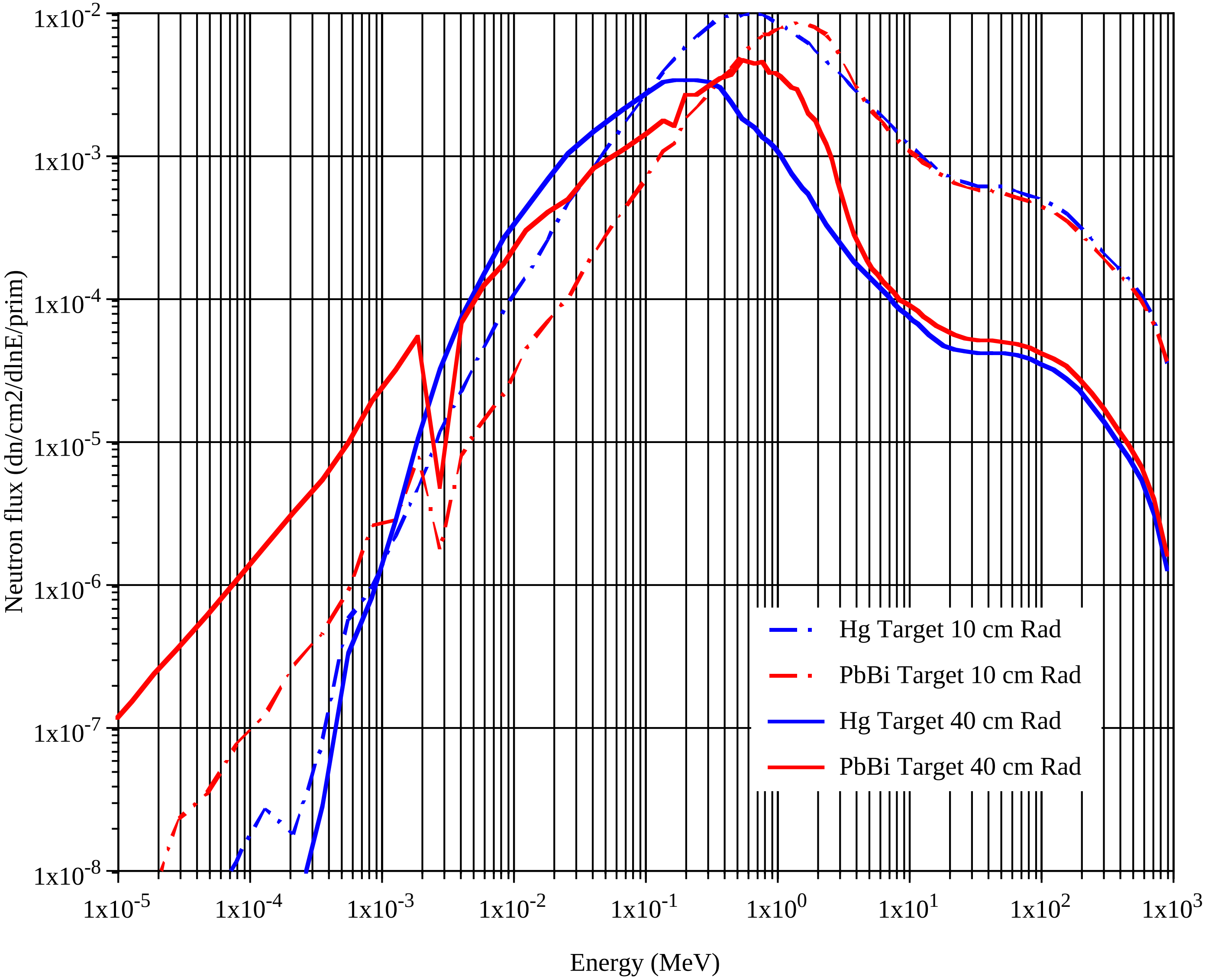
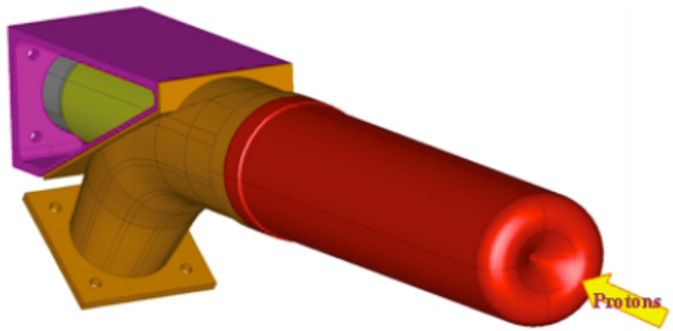


180º Coaxial Bend Target

Basic performances of the target

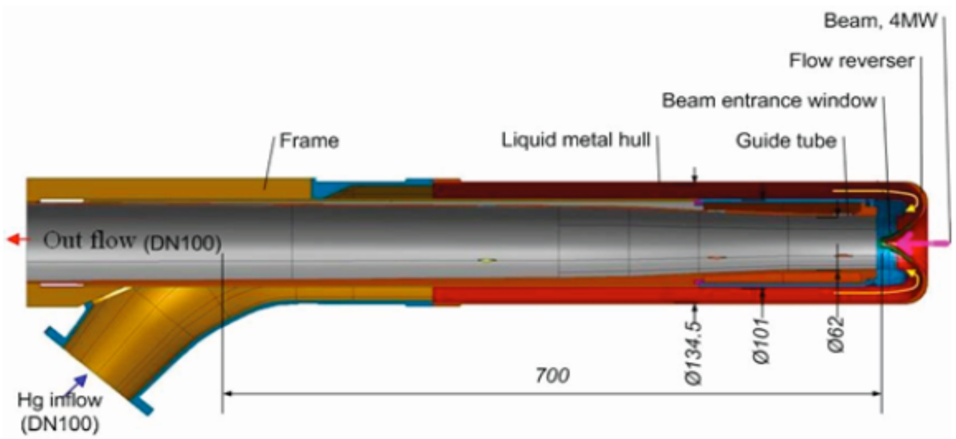
TM-34-07-05 K.Samec /Design of the EURISOL converter target. – PSI 2007

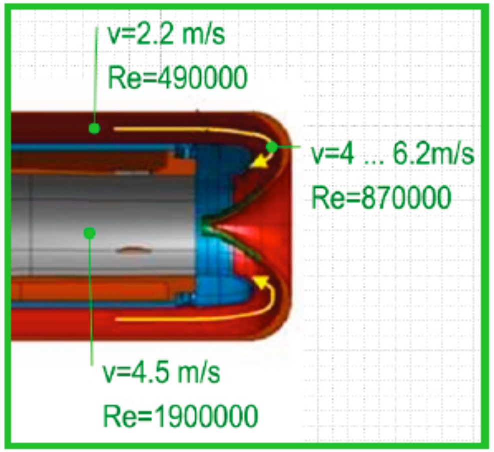


4MW thermal power

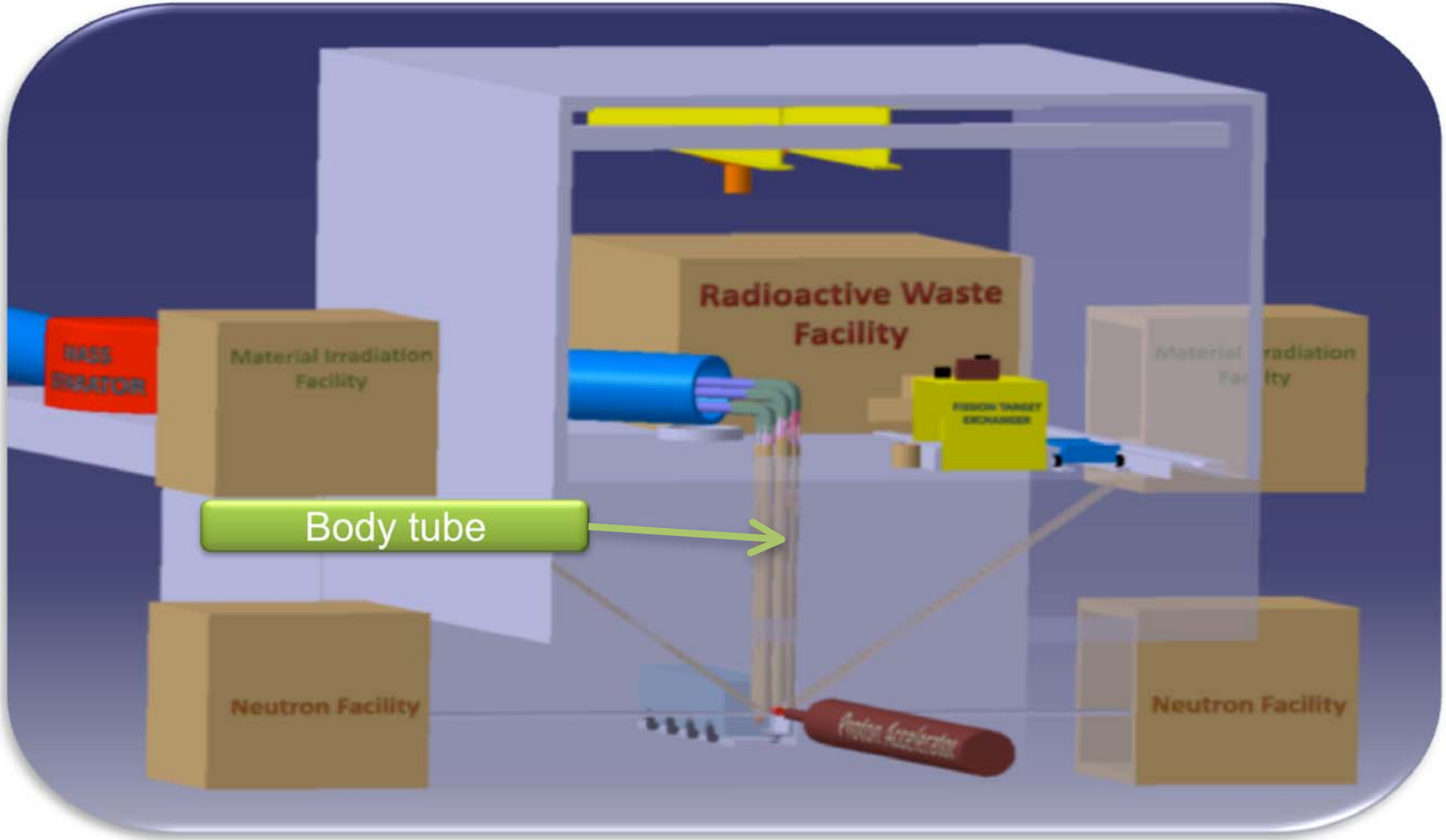
Parameter	symbol	value	unit
Liquid compound	Hg	13.5	kg/l
Flow rate	ϕ	172	kg/s
Entrance temperature	T_{in}	< 60	C
Exit temperature	T_{out}	< 180 > 150	C
Pressure drop	ΔP	< 5	Bar
Static pressure	P_0	< 5	Bar

Ab.13 l/s

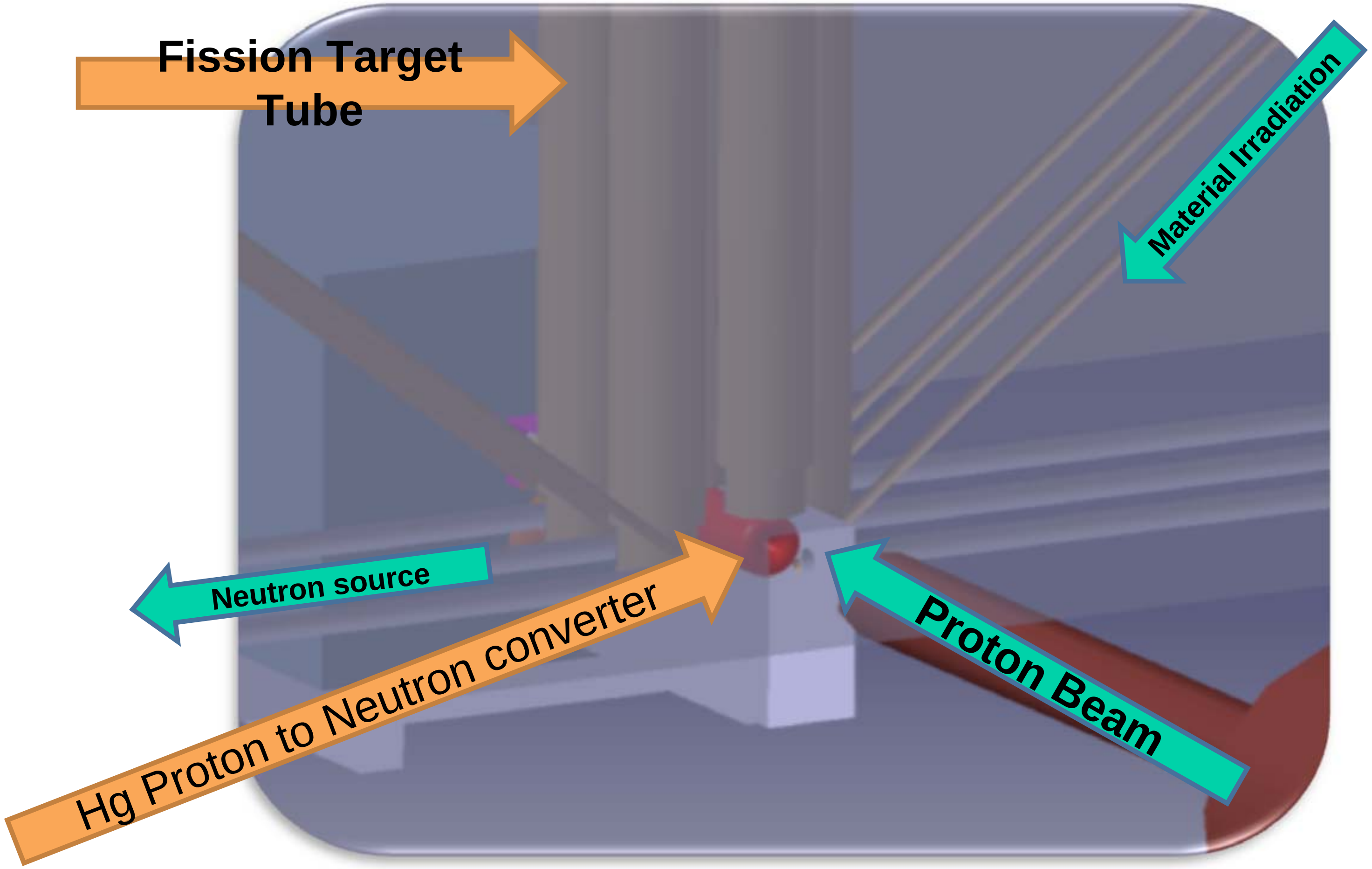




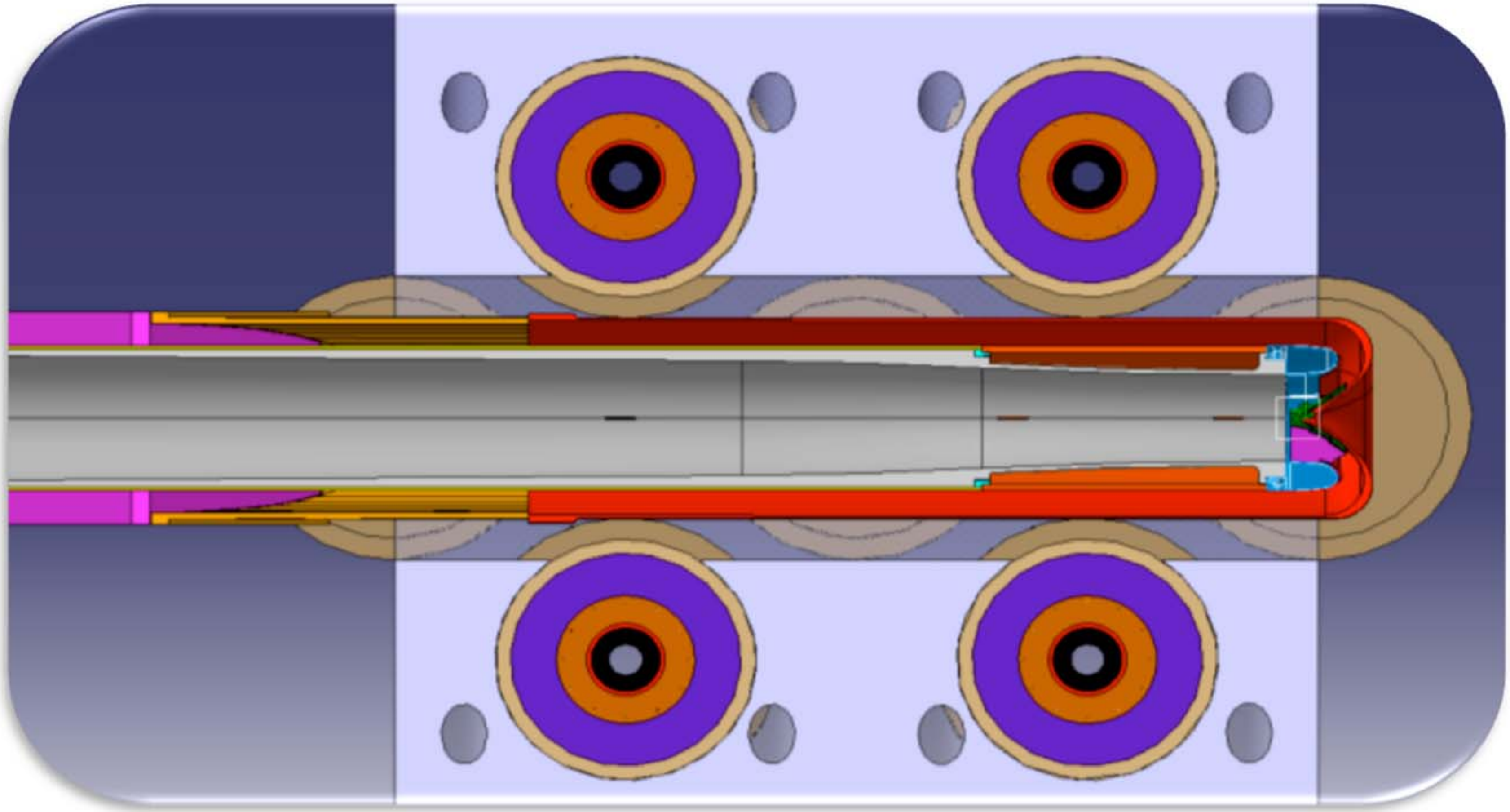
Multi-MW facility Layout



Multi-MW facility Layout



MAFF Fission Target Integration



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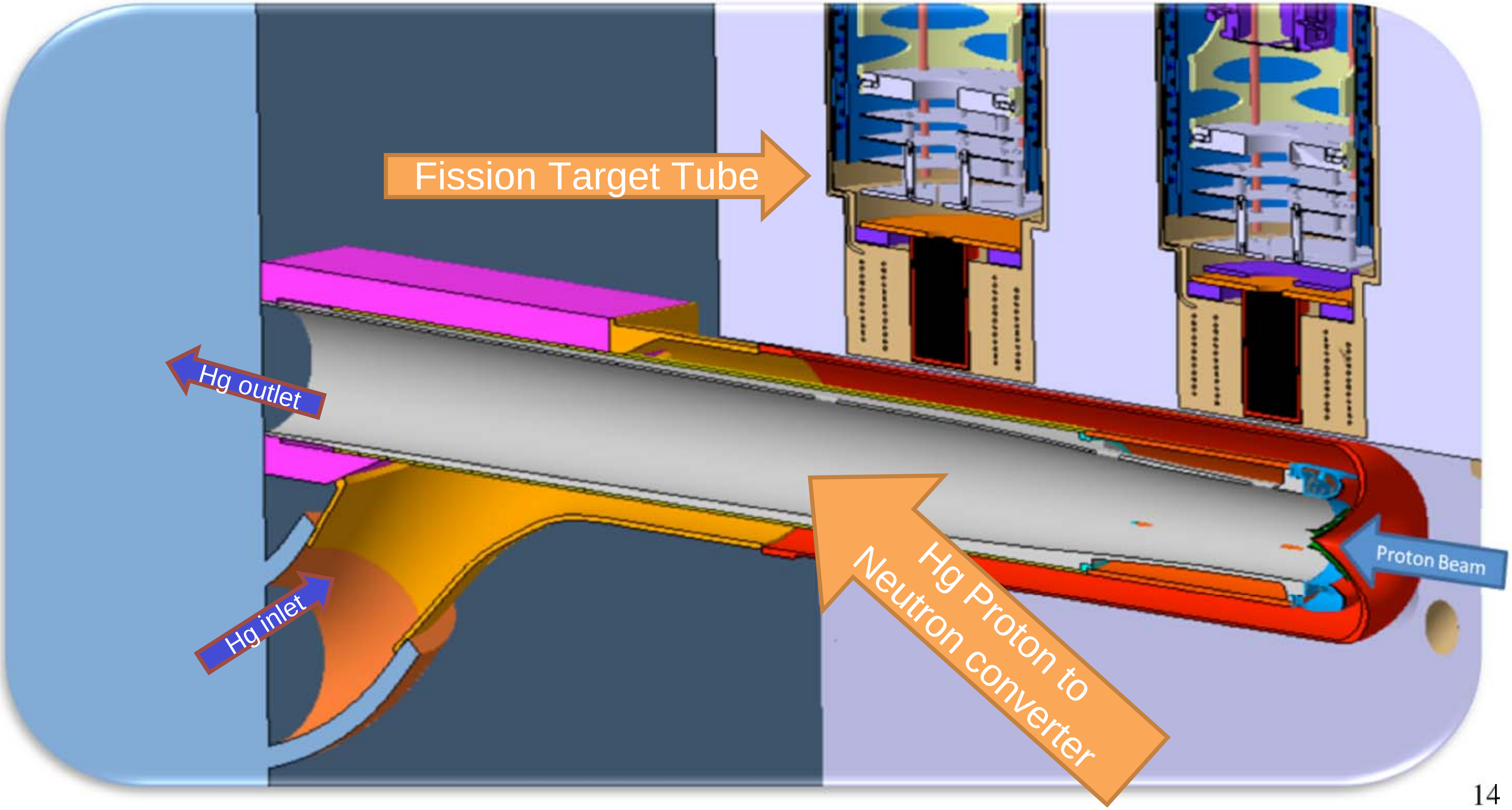
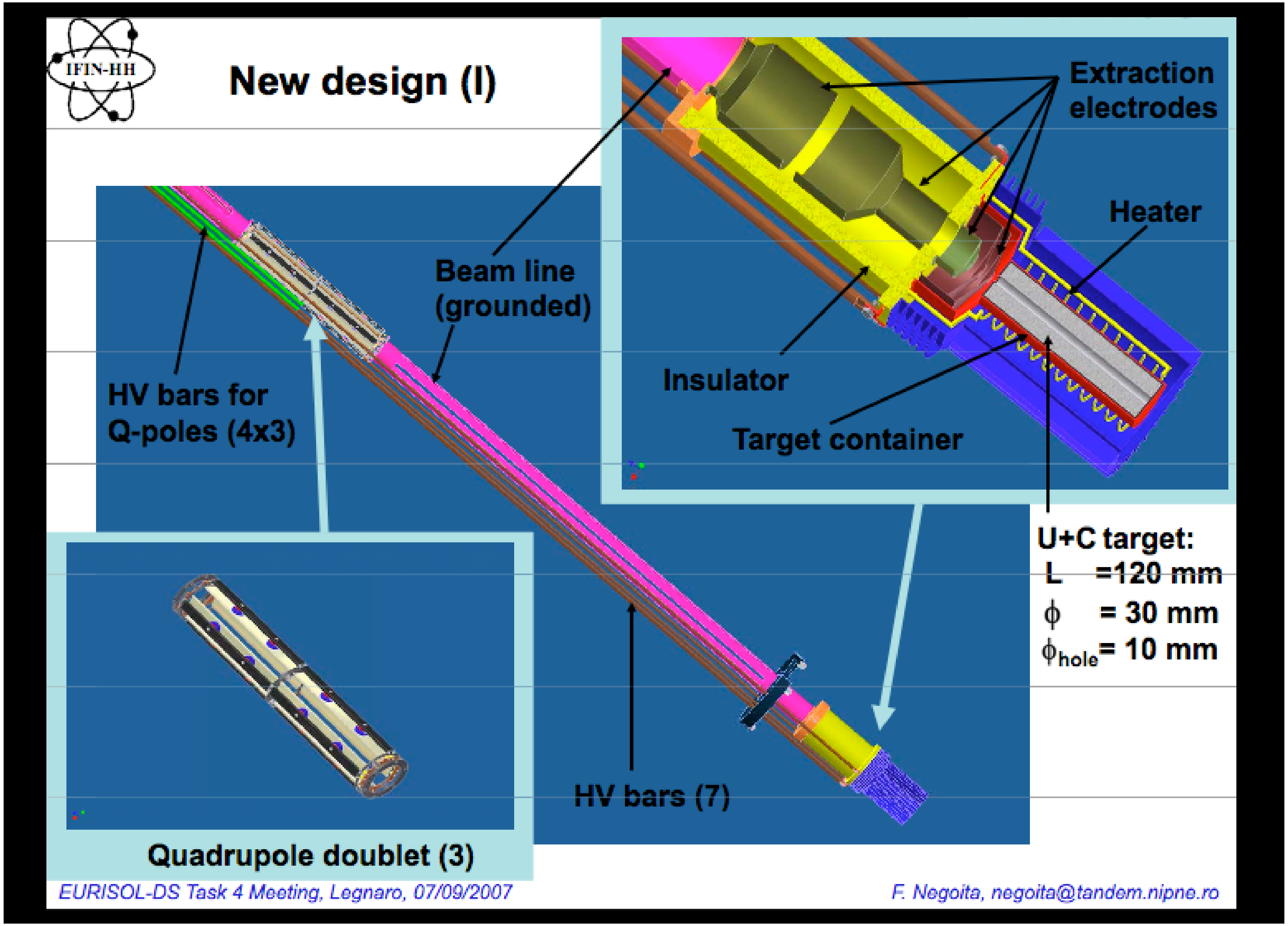


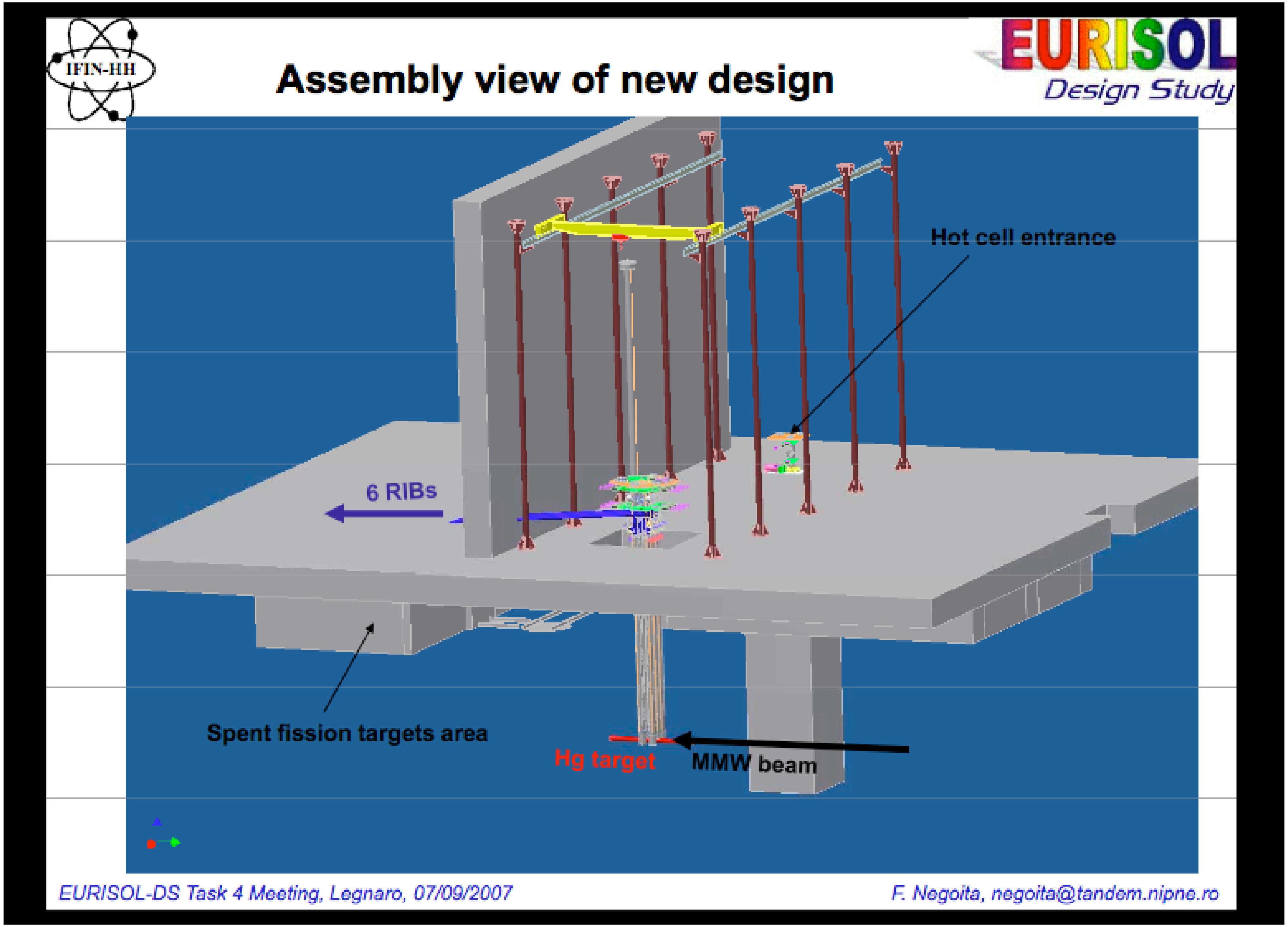
Task#2 – 3D view of the fission target

EURISOL Design Study

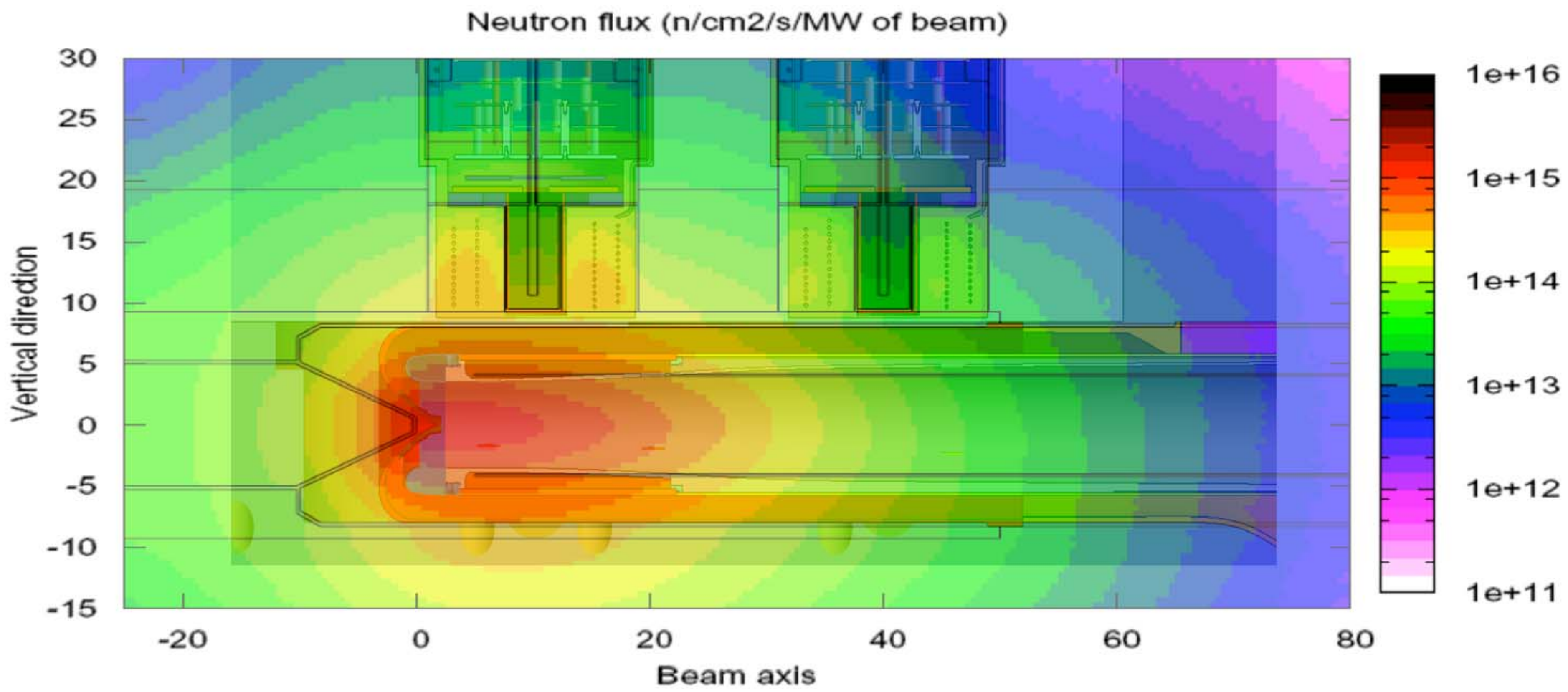


Task#2 – 3D view of the fission target

EURISOL Design Study



NEUTRON FLUX



A) Shielding of the 4 MW target

T. Otto & M. Felcini (CERN)

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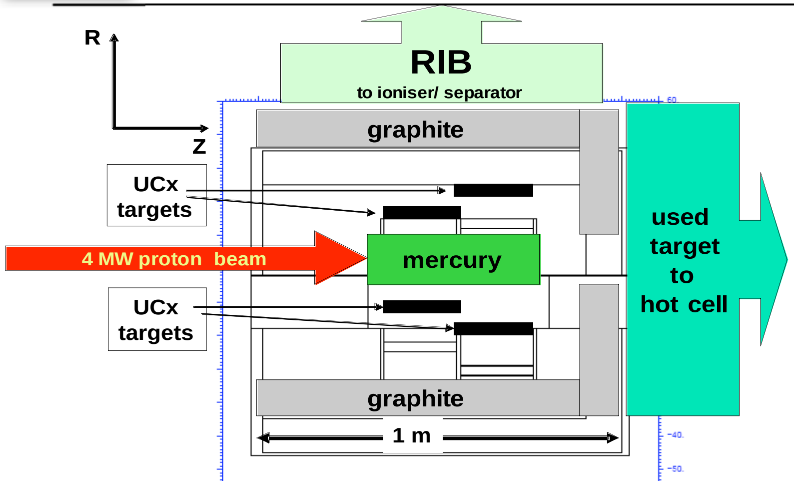
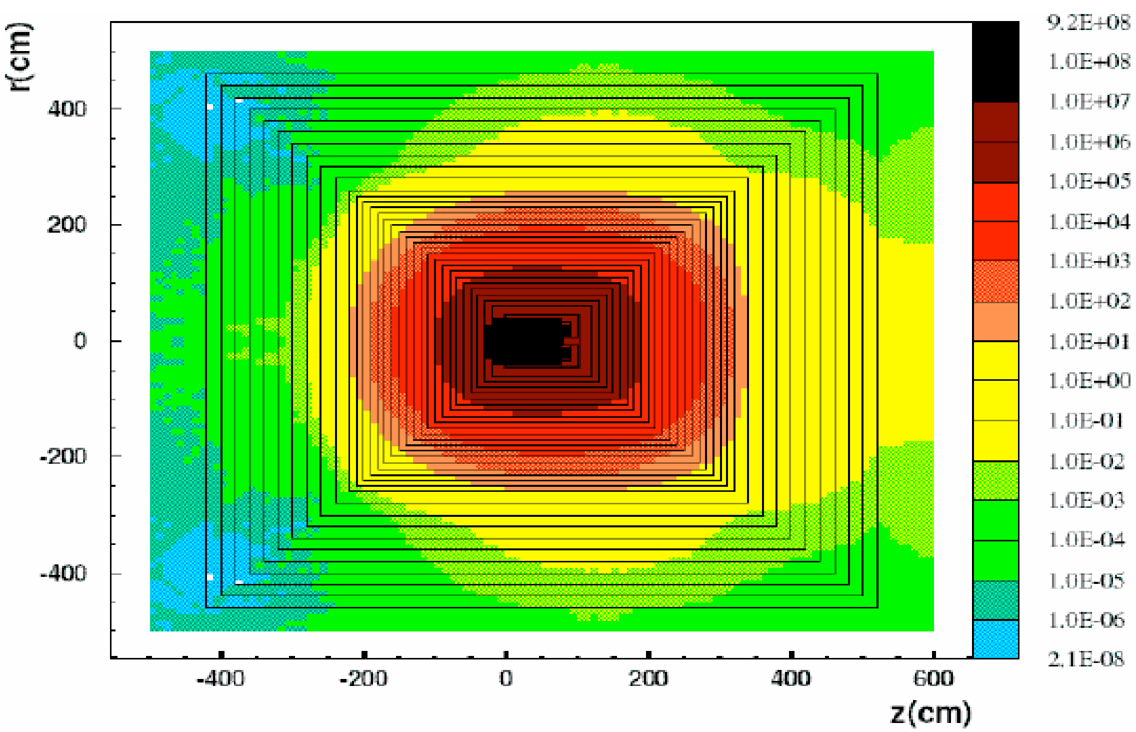
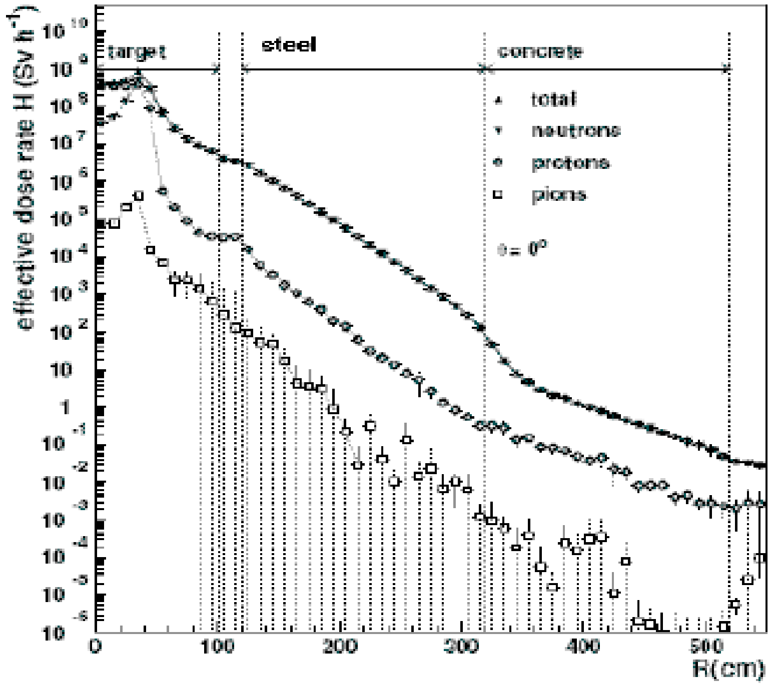


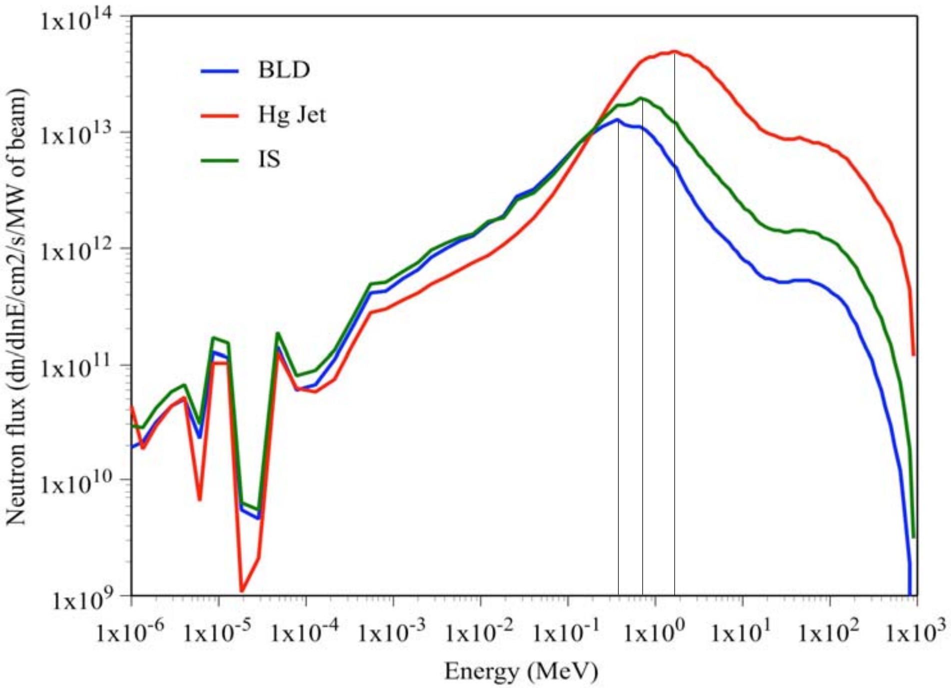
Condition for dose rates < 1 μSv/h

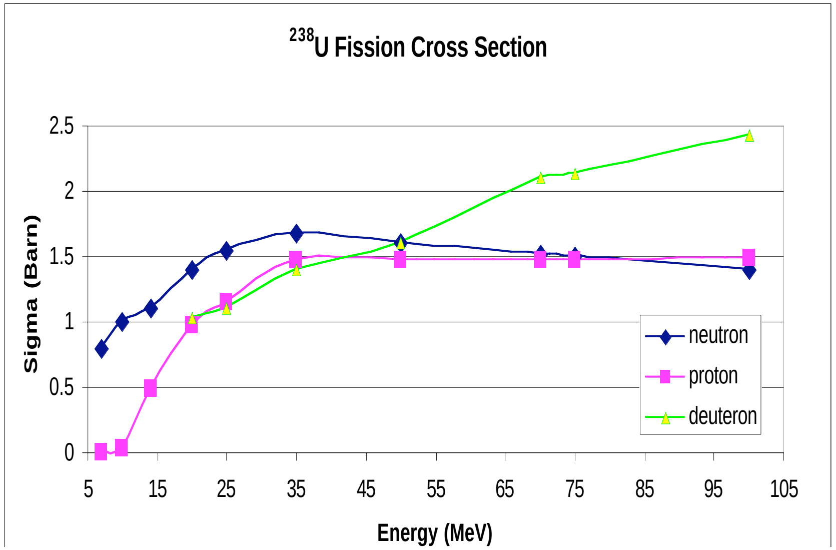
- 2 m of iron
- For θ = 0, 90 &180º → 9.0, 8.0 & 5.5 m of concrete
- To be complemented with earth

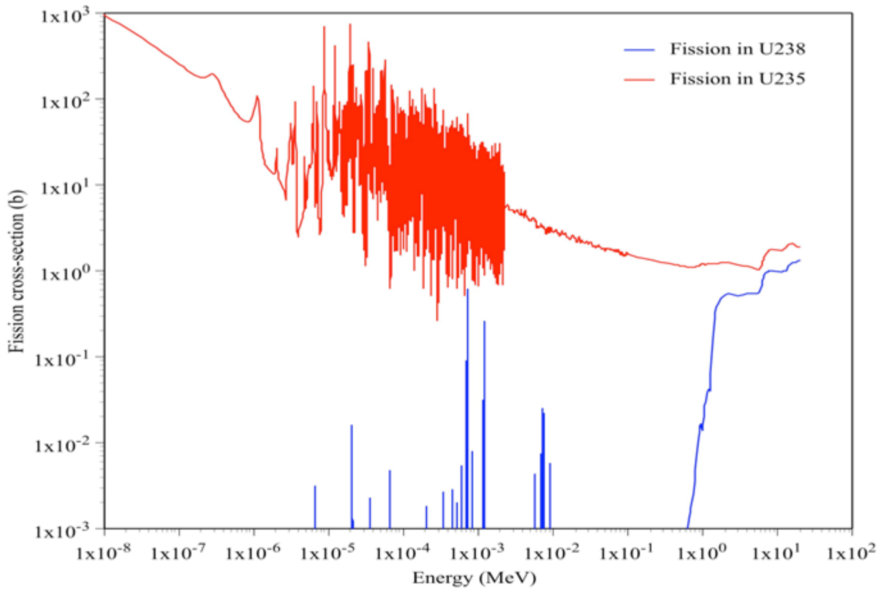




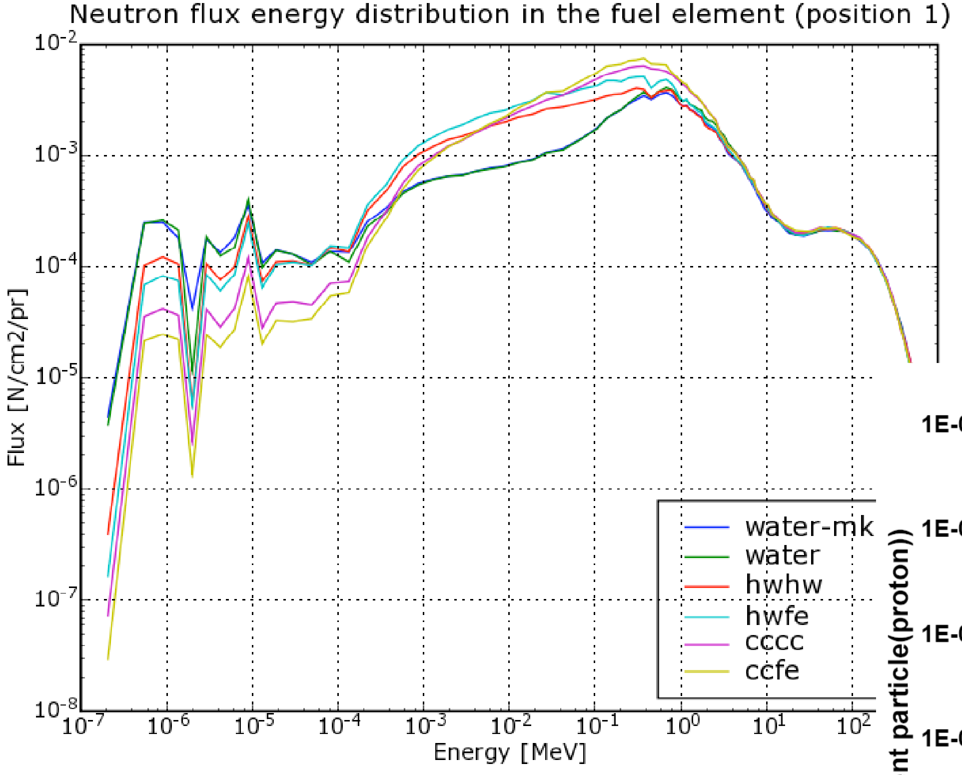
Neutron Energy Spectrum vs Fission Cross-Section in Uranium

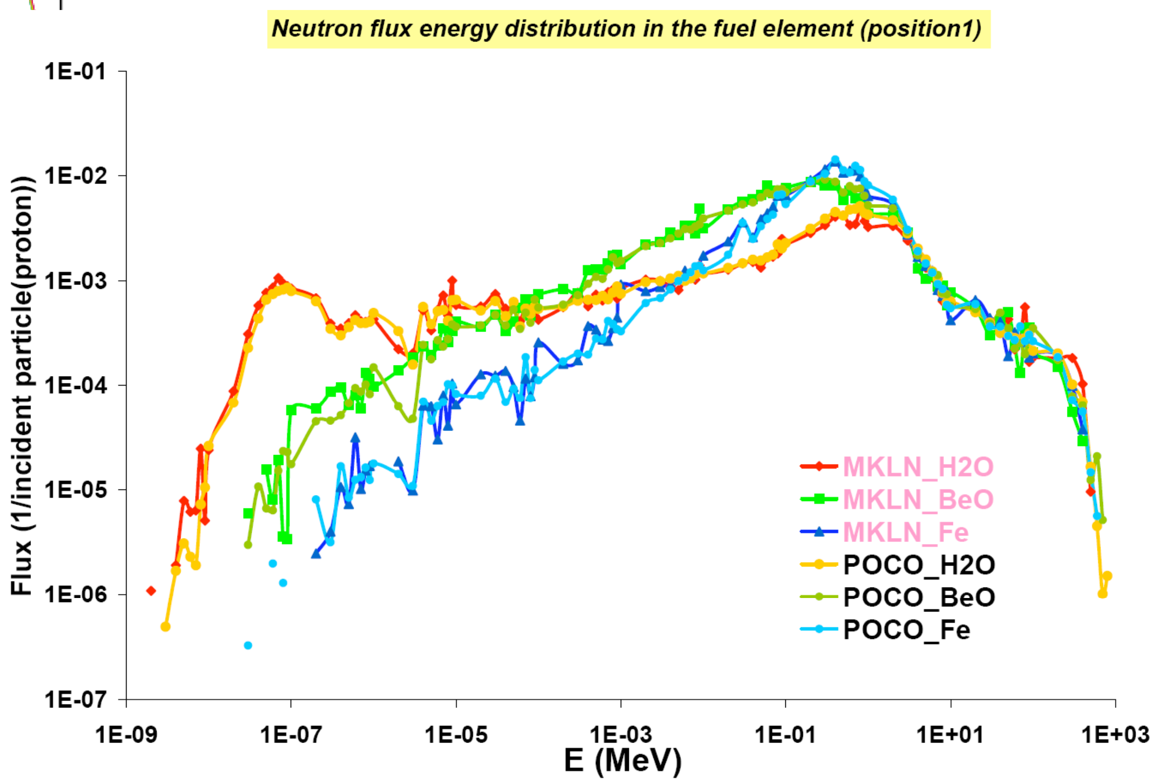




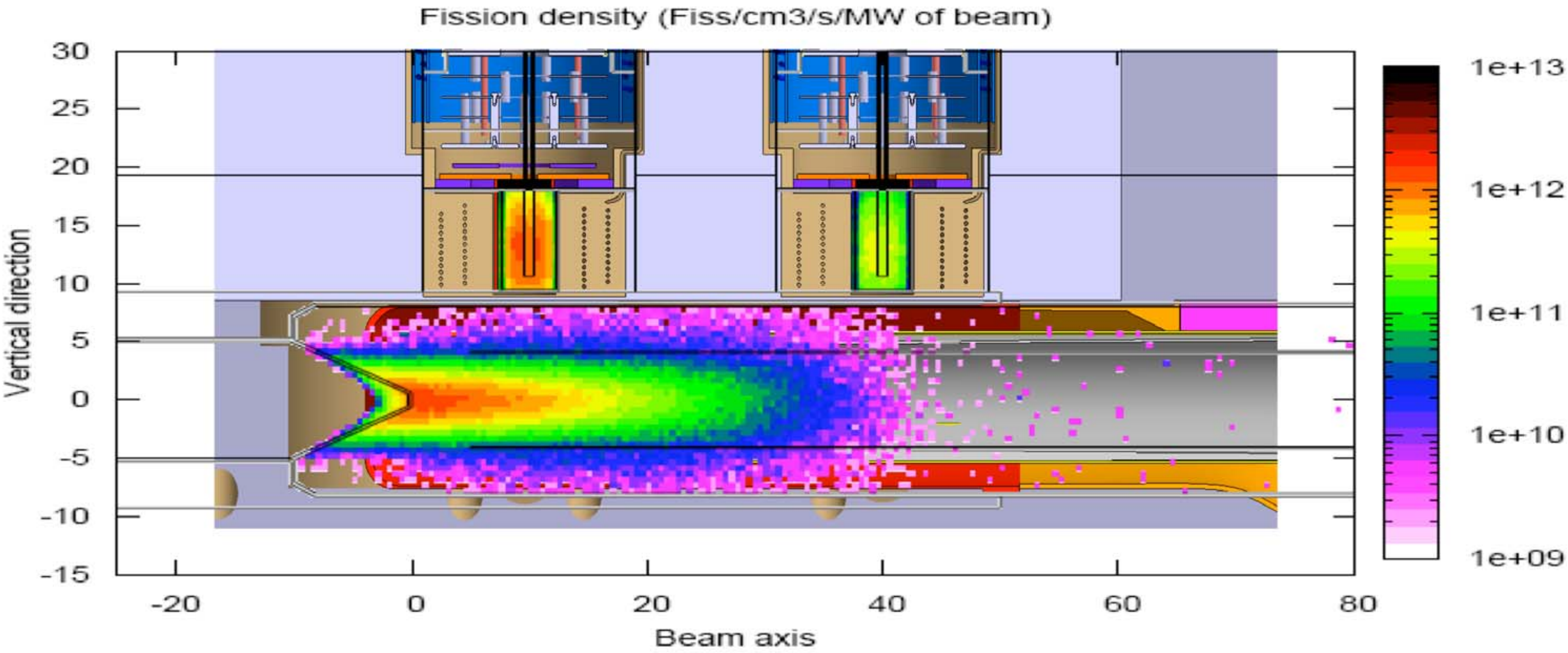


- Significantly harder spectrum for the Hg-J, with a peak neutron energy between 1 − 2 MeV, compared to 300 keV for BLD and 700 keV for IS
- Very low fission cross-section in ^{238}U below 2 MeV (~10^{-4} barns). Optimum energy: 35 MeV
- Use of natural uranium: σ_f in ^{235}U (0.7% wt.): at least 2 barns
- Further gain if neutron flux is reflected (e.g. BeO)


Neutron flux energy distribution in the fuel element (position 1)
Flux [N/cm2/pr]
Energy [MeV]
water-mk
water
hwhw
hwfe
cccc
ccfe


Neutron flux energy distribution in the fuel element (position1)
Flux (1/incident particle(proton))
E (MeV)
MKLN_H2O
MKLN_BeO
MKLN_Fe
POCO_H2O
POCO_BeO
POCO_Fe

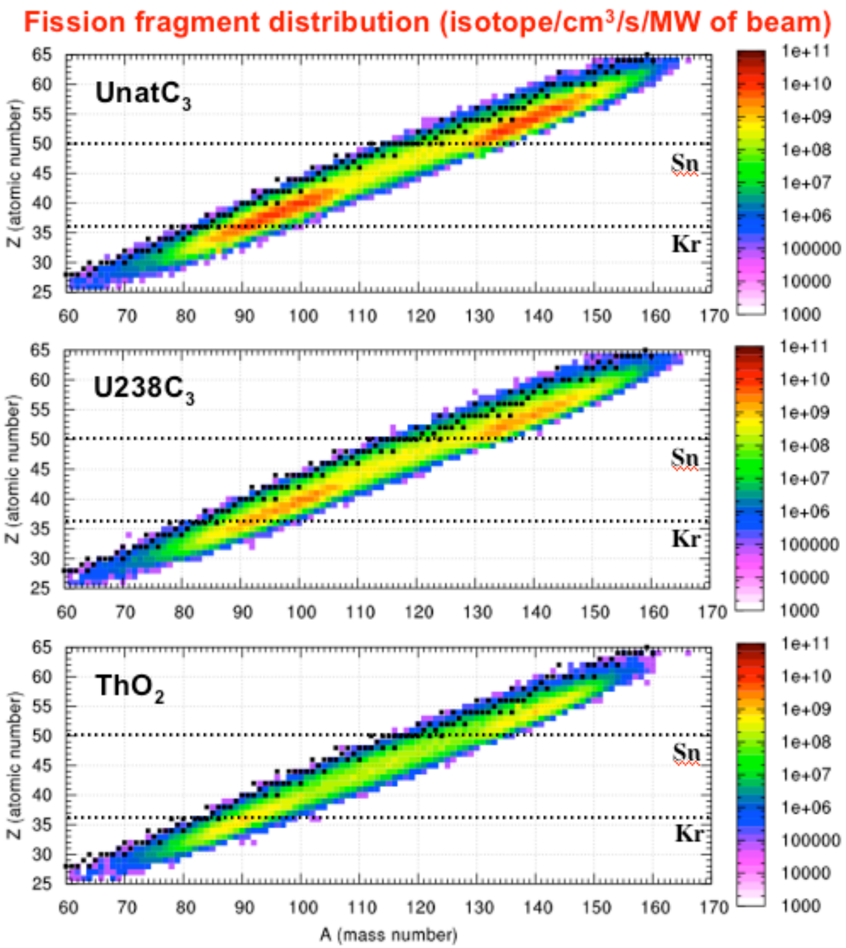
FISSION DENSITY

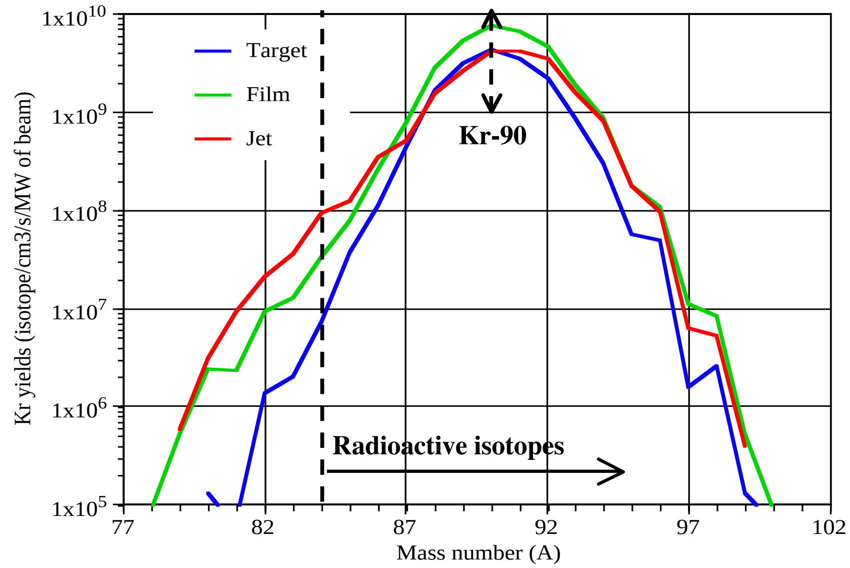


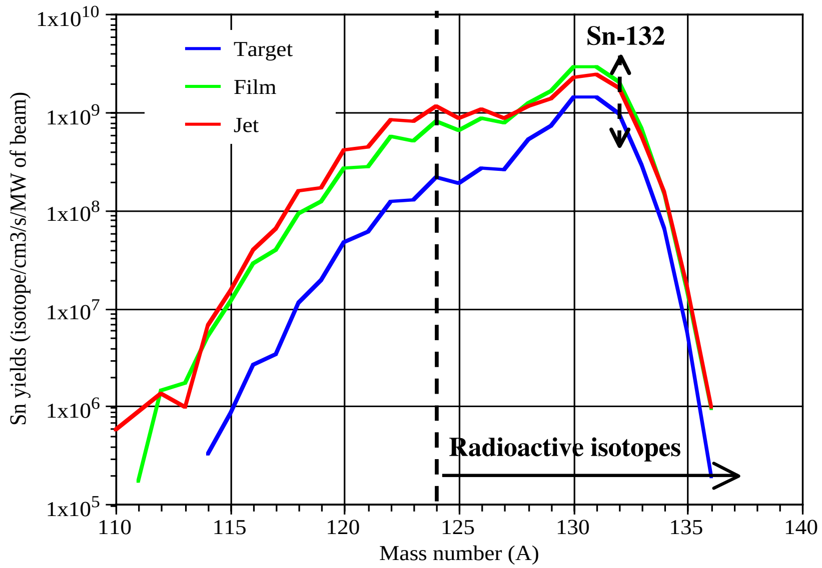
Task#2 – Radioactive Ions Production

EURISOL Design Study

Large RIB production for the proposed neutron-rich isotopes.
Clear advantage in using natural uranium.
Possibility of investigating the lower end of the *terra incognita*, e.g. Nd-157, Tb-167

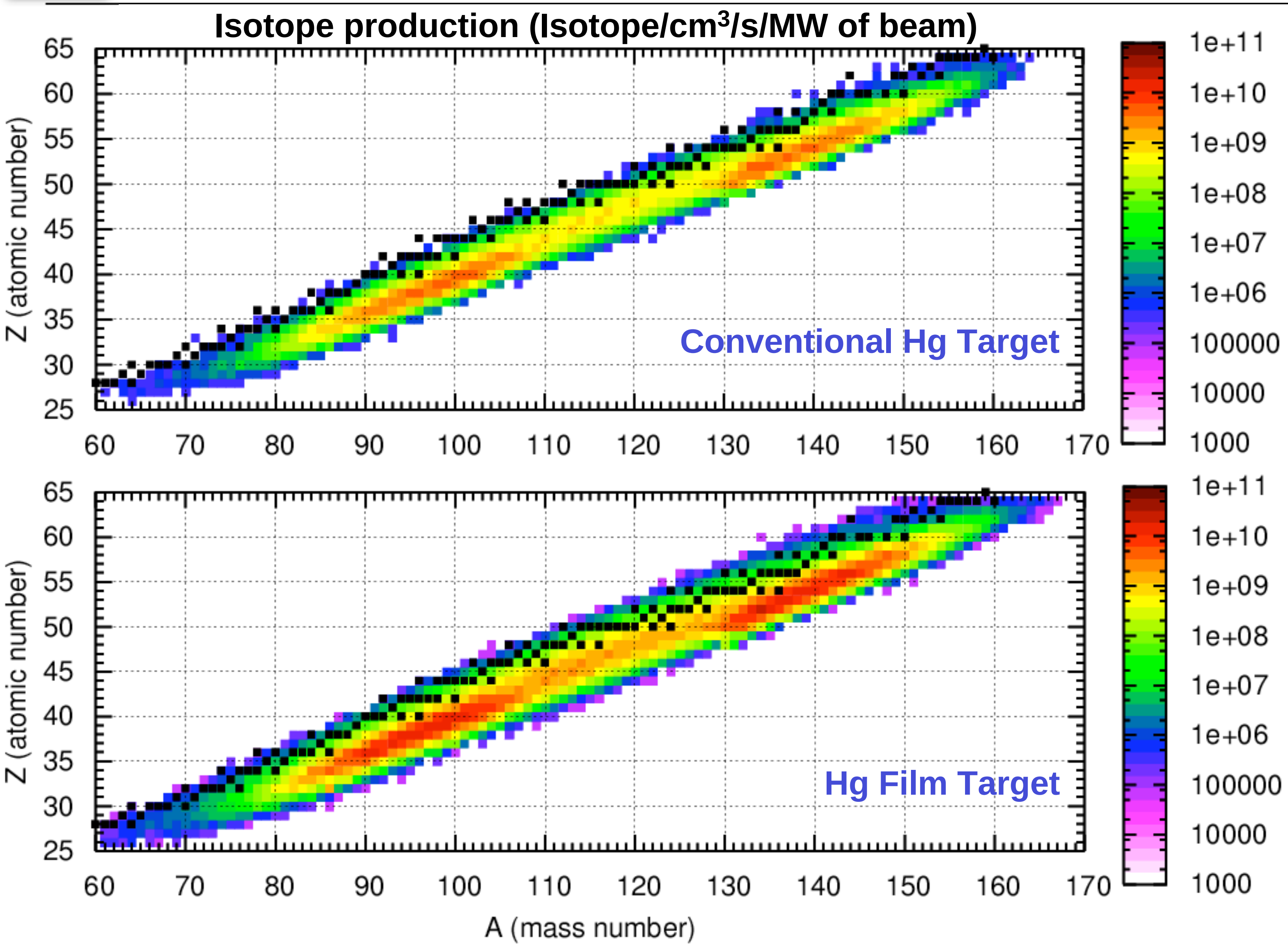






Radioactive Ions Production

EURISOL Design Study

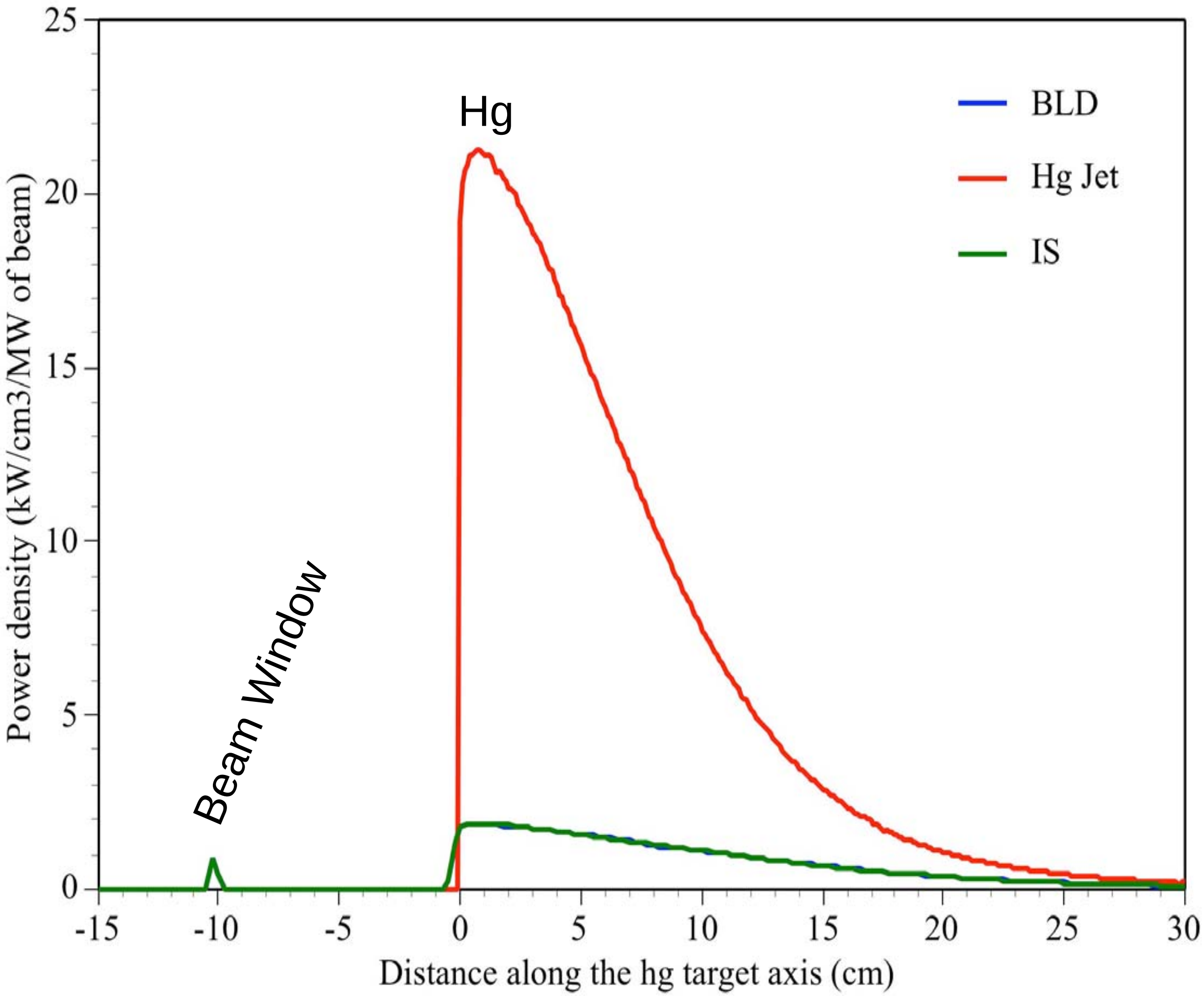


UC$_3$ Targets:

- **Natural Uranium (0.7% U-235)**
- **Density: 3 g/cm^3**

Power Densities (2)

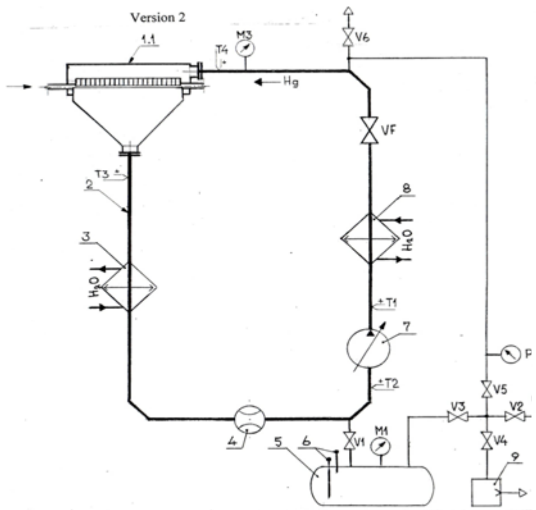
- More than one order of magnitude difference between the free surface Hg-J (~22 kW/cm^3/MW) and the confined Hg targets (BLD, ~2 kW/cm^3/MW)
- BDL and IS: Beam window suffering important power densities (~1 kW/cm^3/MW → extra cooling plus radiation resistant material needed)
- Peak power densities similar to ESS and SNS



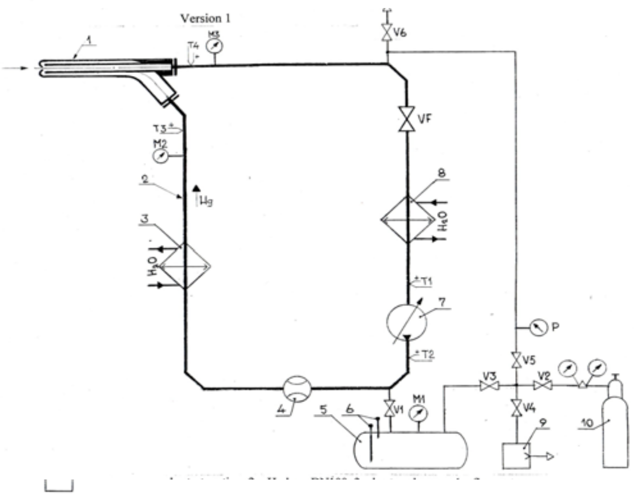
Liquid Hg Loop for tests of target mock-ups and other components

EURISOL Design Study

IPUL variant

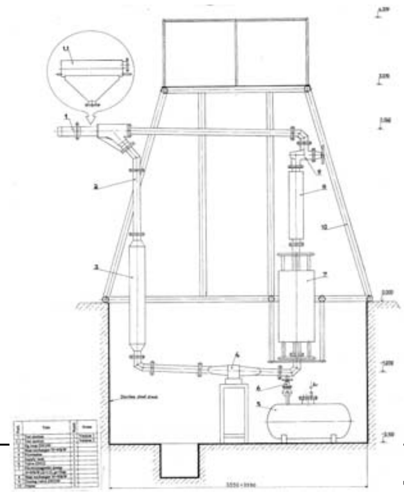


PSI variant



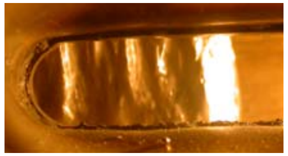
Existing Hg – loop in Institute of Physics (under reconstruction)(parameters of EMP p=4 bars; Q~12l/s

1 – test section; 2 – Hg loop DN100; 3 – heat exchanger; 4 – flowmeter;
5 – supply tank; 6 –level meter; 7 – electromagnetic pump; 8 – heat exchanger;
9 – vacuum pump; 10 – argon vessel; M1…M3 – pressure meter; P – vacuum gauge; T1…T4 – thermocouple; V1…V6 – valve; VF – dosing valve;



Experiments of Hg "curtain" in InGaSn Loop

Transverse Hg – film



a

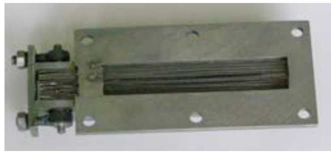
b

c

Modules of transverse film injectors

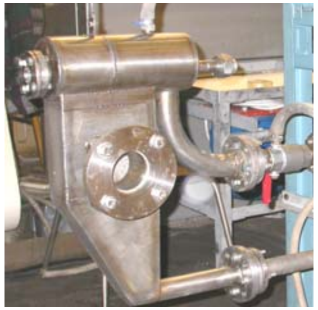
a

b



c

Test chambers



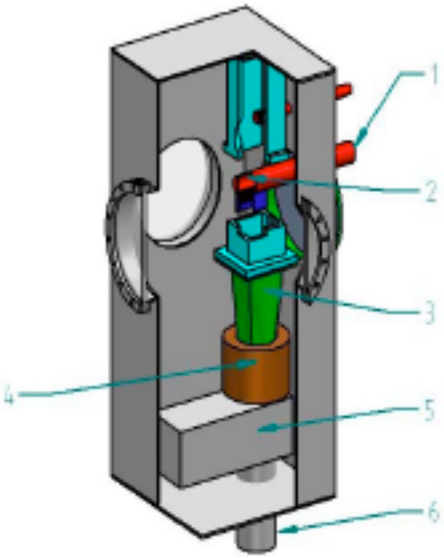
InGaSn test loop of transverse film target module

P=3 bar; Q~1.5 l/s

a – with rectangular cell inner structure
b – with round cell inner structure
c – with parallel separator inner structure

Liquid Hg Loop – Transverse Film

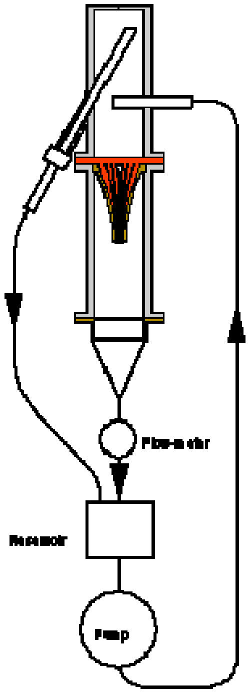
EURISOL
Design Study

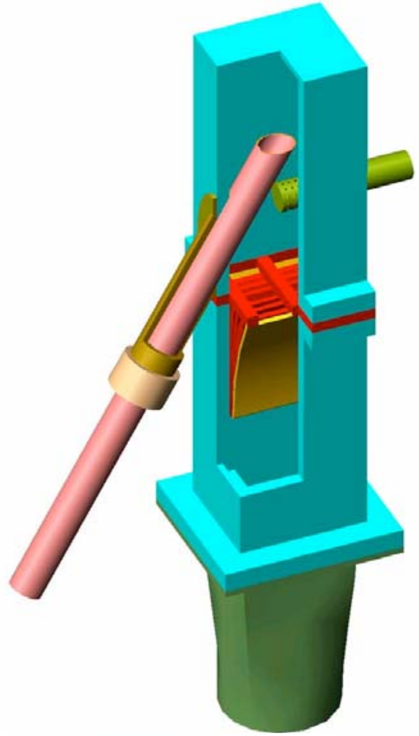


a) principle scheme

b) head of transverse film injector

Fig.19
Experimental unit of transverse film injector
1 -inlet tube; 2-transverse film former; 3- liquid metal distributor; 4- flowmeter; 5- supply tank; 6- outlet tube.

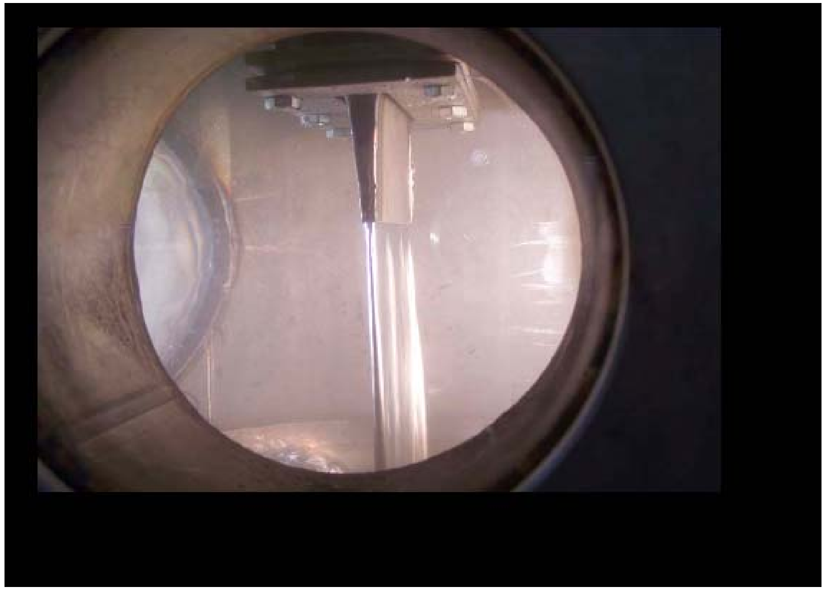




Task#2 – Prototypes & Experiments (D3,4)

EURISOL Design Study

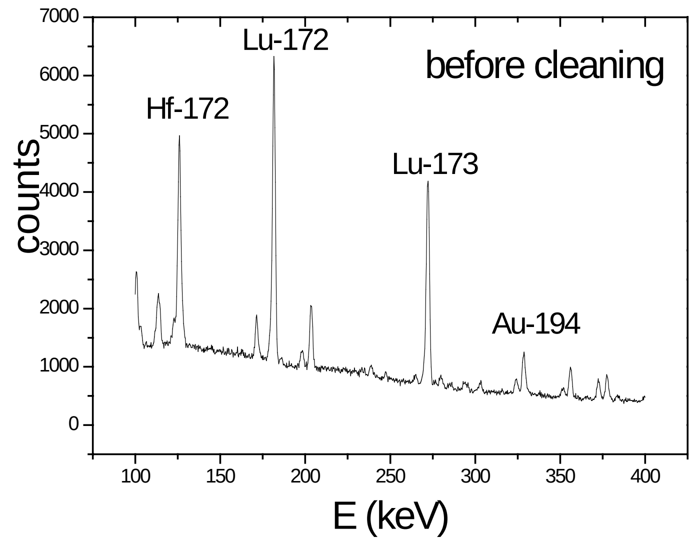
Engineering design and construction of a functional Hg loop (D3)

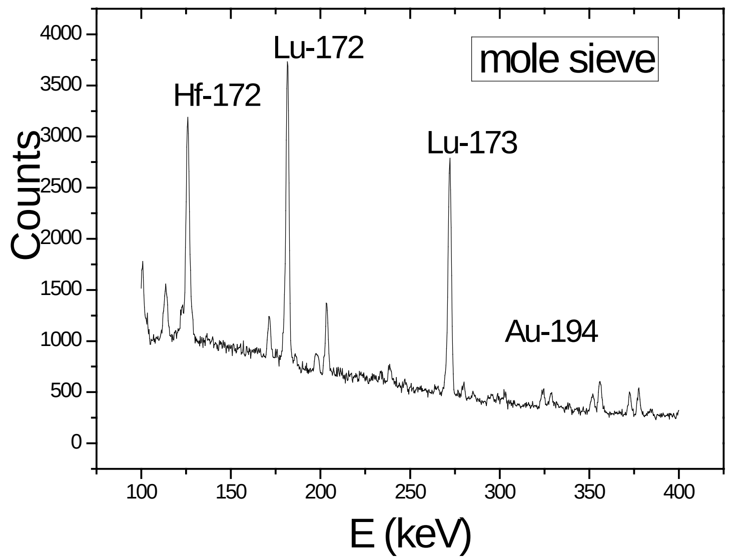


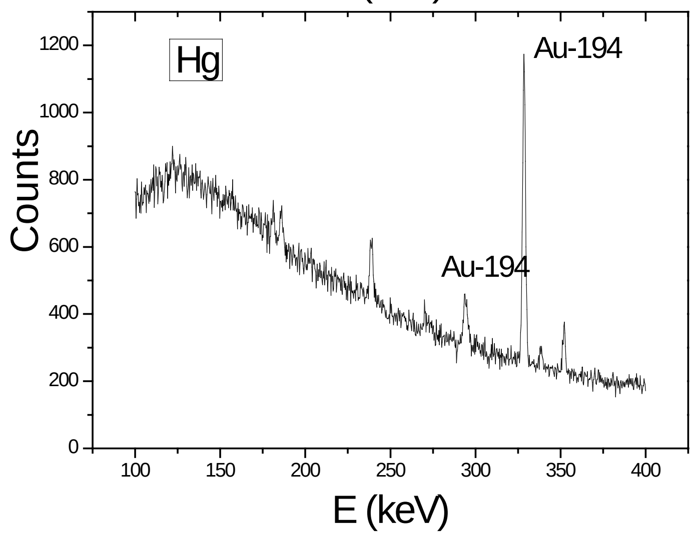
Task#2 – Hg Waste Management (D2)

Removal of Lu and Hf from CERN-Hg irradiated sample

- Hf and Lu present as an oxide deposit on Hg were removed by contacting the liquid metal with oxide materials with a rough surface:
- Sintered corundum
- Molecular sieve
- Oxides stick to the surface of these materials







B) Activation of Hg

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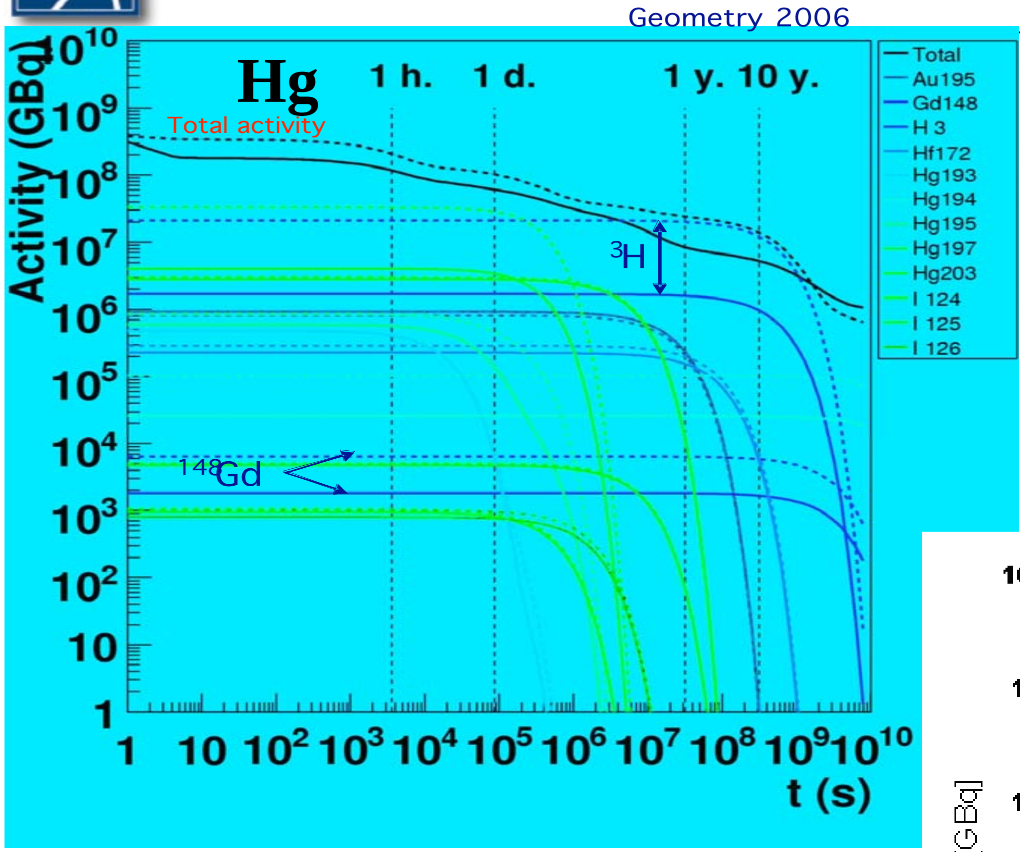
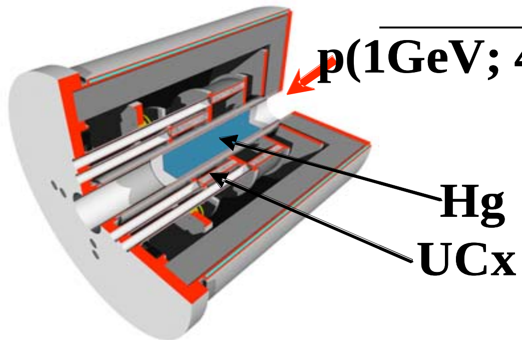
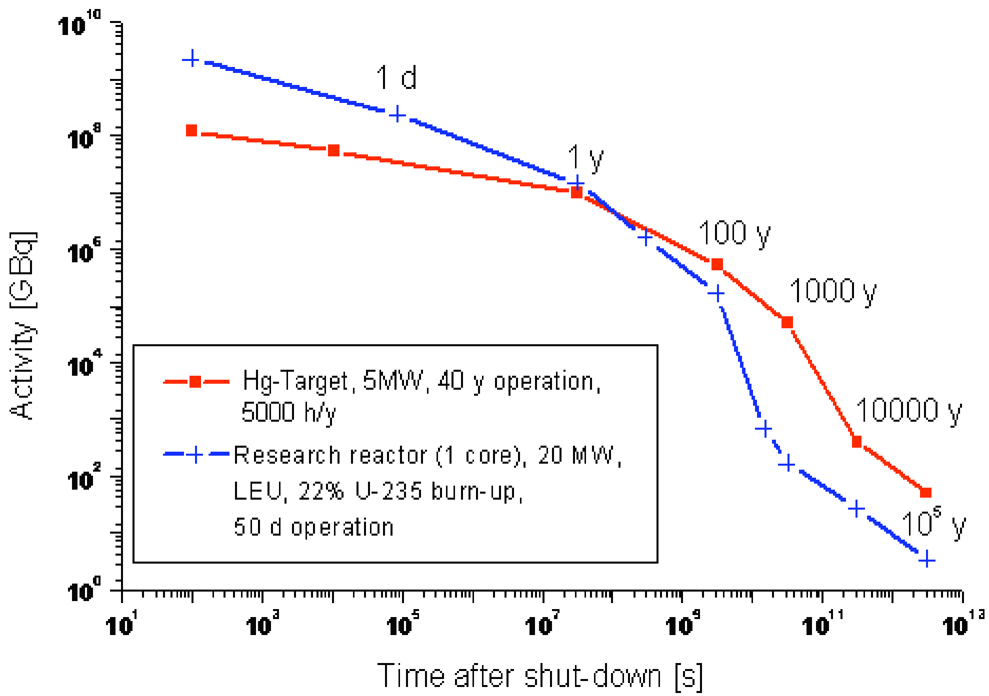




➩ Irradiation : 40 years operation, 5000 h/year, 4MW beam power



→ induced activity comparable to the research reactor + α emitters

B. Rapp et al. (CEA)

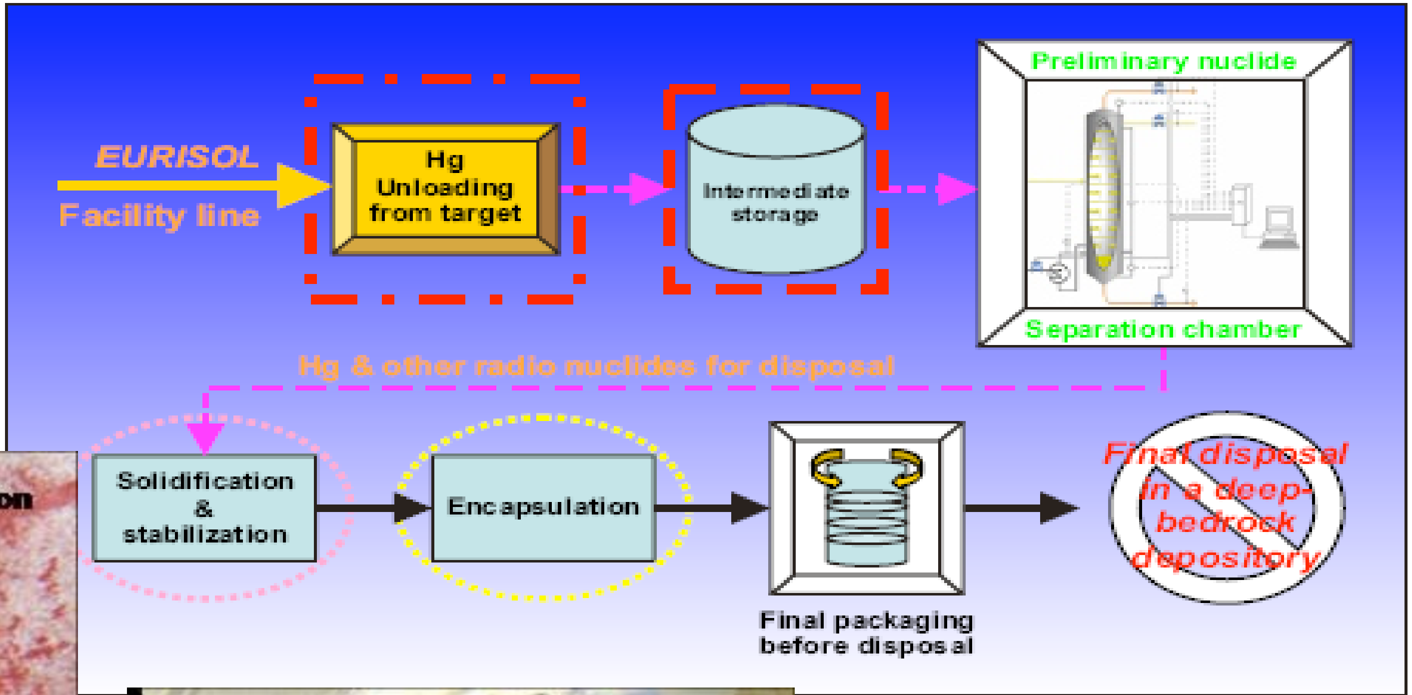
D) Disposal of liquid Hg

EURISOL Design Study

R. Moormann, Chiriki et al. (FZJ)

A schematic layout for liquid Hg-target disposal strategy

Chemical stabilization of Hg as an inorganic compound, e.g. HgS, HgSe, HgO, Hg_2Cl_2, $HgCl_2$



Extrapolation from laboratory scale to "industrial" scale still to be done

Summary and Outlook

- A conceptual lay-out of the new target station with all target positions and neutron facilities is proposed.
- Detailed neutronic and release studies have been carried out for different combinations of moderators and fission target composition
- Safety issues for both the fission target and proton converter are being addressed
- In parallel a detailed study of some alternative solution which would allow a much more compact geometry of the fission target arrangement is under study. (transverse film, Hg jet, etc…)

Thank you for your attention and to all contributors...